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Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a Council Meeting held on June 21st:—

Associate Fellow.—Captain L. H. Mander, F.R.G.S.
Student.—C. H. R. King.
Member.—Captain the Right Hon. F. E. Guest, C.B.E., D.S.O., M.P.
Foreign Members.—Lieut. Esteban R. Zanni, Lieut. Cmdr. G. Hara, I.J.N.

It is regretted that the announcement of the election of Mr. Donald Smith as an Associate Member of the Scottish Branch was omitted from the June announcements.

Election of Chairman.

Lieut.-Col. Mervyn O'Gorman, C.B., F.R.Aë.S., was declared duly elected Chairman-elect at the Council Meeting, held on June 21st. He will assume office on October 1st, when Air Commodore H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C., the present Chairman, becomes Vice-Chairman.

Admission of Associate Fellows.

In order to carry into effect the new regulations for the admission of Associate Fellows adopted at the Annual General Meeting, the Candidates' Committee has been engaged upon drawing up a syllabus for the Society's examinations, which will be published in full in a forthcoming issue of the Journal, it now having been adopted by the Council. The syllabus provides for candidates' examination in the following subjects:—

PART I.
(*a*) English.
(*b*) French, German, Italian, or Spanish.

PART II.—One paper in any two of the following subjects, to be selected by the candidate.
(*a*) Strength and Elasticity of Materials, and Theory of Structures.
(*b*) Aerodynamics.

(*c*) Heat Engines.
(*d*) Meteorology and Navigation.
(*e*) Mathematics.
(*f*) Chemistry and Metallurgy.

The Council have decided that, for the present, each paper will contain a large number of questions in order to give a wide choice of tests of the candidate's knowledge.

The Council have further decided to accept an approved course of aeronautics at a University or Technical College as part of the two years' qualifying experience in the application of the science of aeronautics—required by the regulations in addition to examination results—the total allowance in such cases not to exceed one year.

Details of qualifications giving exemption from either Part I. or Part II. of the examination will be found in Clause IX. of the Regulations.

The first examination will be held in April, 1922.

A list of books recommended for Students has been drawn up, of which copies may be obtained on application to the Secretary.

Summer Vacation.

Members are notified that the Offices of the Society, including the Library, will be closed for annual cleaning from Saturday, July 30th, to Monday, August 8th.

W. Lockwood Marsh, *Secretary.*

PROCEEDINGS.

TENTH MEETING, 56th SESSION.

The Tenth Meeting of the 56th Session took place in the Hall of the Royal Society of Arts, London, on Thursday, March 3rd, 1921, Air Commodore E. M. Maitland presiding.

The CHAIRMAN introduced Major T. Orde Lees by saying that he was a remarkable man of restless energy and that he loved a spice of adventure. No sooner had he come back from his South Pole expedition with Sir Ernest Shackleton in 1915 than he set about joining up in the Air Force as a pilot. They said they could not take him on as a pilot because he was too old. He then set about saving the lives of aeroplane pilots by parachutes, and had devoted himself to that cause ever since. At first he could not get an aeroplane on which to commence his experiments, and he had to lead off by jumping off the top of the Tower Bridge, 153ft. in height, which successfully demonstrated that the type of parachute he used was a very quick opening one. From that time onwards he had been assiduously throwing himself out of every form of aeroplane and from kite balloons, and also studying the problems of parachutes. He thought that he was right in saying Major Orde Lees had done more practical parachuting from aeroplanes than anybody else in this country except Miss Boyden.

Major T. ORDE LEES then delivered the following lecture:—

SAVING LIFE IN AIR WRECKS.

When the aeroplane came into being ten years ago the parachute had no place in the practical politics of aeronautics.

The extensive use of observation balloons, throughout the war, brought the life-saving capabilities of the parachute to the front.

In pre-war days the parachute was regarded almost exclusively as a medium for daring displays.

Public interest has been aroused by the fact that the lives of over 800 men were saved from balloons by parachute and many more might have been saved from aeroplanes by the provision of this simple appliance.

For the last six months of the war the Germans were using a comparatively crude type of parachute in nearly all their aeroplanes. This equipment was entirely optional. Nine out of ten pilots elected to carry them. According to the best information I can get, of the pilots who had occasion to use them, nine out of ten saved their lives.

I was in Berlin in November last and had long personal talks with five independent German pilots. Making every allowance for patriotic exaggeration on the part of my German informants, one must concede, from the reports of our own airmen, that at least five out of ten German pilots who resorted to their parachutes were saved. If only one in ten had been saved, the carrying of parachutes becomes both a humane and a man-economising proposition.

One of the biggest objections to the fitting of parachutes—their effect on that elusive quality of a machine termed " the performance "—seems to have been quite disregarded by the Germans. All war fliers appreciated the critical value of superiority of speed and climb. The weight of a 28lb. parachute makes an

appreciable difference, two parachutes a material difference on a D.H.4 for instance. One parachute reduces the speed by 1½ per cent., two by nearly 2 per cent. The climb is reduced 50 feet and 75 feet per minute respectively. A large passenger machine fully equipped would probably be less affected.

The fear that aviators might be tempted to resort to their parachutes prematurely when, by sticking to their aeroplane, they might succeed in saving it seems to have had no foundation in fact amongst the German fliers. From what I know of British fliers I think it would have less amongst them. Still, the suggestion has been advanced as an argument against fitting parachutes.

During the war I estimate that about 200 British pilots were seen to jump without parachutes from their burning machines at high altitudes rather than be roasted to death in mid-air. All were killed. Nearly all would have been saved if they had had parachutes, because they all proved that they were able to get out and jump and because a burning machine can be kept on an even keel until the last minute.

It has often been said that parachutes will act with certainty only when the machine is on an even keel and conversely that when the machine is on an even keel they would never be required. Well, there are about 200 cases where the doomed aviators demonstrated that they could make good their exits. Everyone in the Air Force knows of several cases of this happening, if they have not actually seen it with their own eyes. Two hundred is merely an estimate, but I can quote chapter and verse for three cases, two in war and one in peace, which must convince the most sceptical that the provision of parachutes would have saved the lives of two men whose great experience and ability in the air made them of real value to their respective countries.

The first is Major Lufberry—the American fighting Ace. Enemy action ignited his machine at 2,500 feet. For 2,000 feet he struggled to extinguish the flames and keep the machine under control. At 500 feet, unable to withstand the torturing heat any longer, he was seen deliberately to get out of his machine and jump to earth.

Lieutenant Berkeley, of the Coldstream Guards, was one of the very few British pilots who had ever made a parachute descent from an aeroplane. He did so in October, 1918. Three months later, in my presence, he collided in the air. The other machine, a single-seater, got away and made a lucky landing without an under-carriage.

Lieutenant Berkeley had a passenger. If both had had parachutes, both could easily have used them as the collision happened at over 2,000 feet. The right wing of the two-seater was badly broken. The machine was out of control all the way down, swerving this way and that but, for appreciable periods, righting itself and giving ample opportunities for the aviators to use parachutes. They had none. The pilot was killed, the passenger survived in spite of serious injuries. On this occasion fire did not break out on impact with the ground, as it so often does.

The third case is that of Peter Leigh. His machine burst into flames at only 200 feet above the houses at Finchley. He at once got out, apparently misjudged his height, and attempting to use his coat as a parachute, jumped. Successful parachute jumps have been made from less than this height. Peter Leigh clearly showed his ability to use a parachute even at a low height. He was killed.

To mention but a few amongst famous aviators who met their deaths in accidents where parachutes might have spared them, we have Lieutenant Warnford, V.C., Captain Ball, V.C., Pégoud, Cody, Professor Hopkinson and Major Gooden, the popular Farnborough test pilot, who had made a number of parachute descents from balloons before the war. He was killed by a wing breaking off in mid-air.

Whilst parachutes could have been used in thousands of cases during and since the war, it must be admitted that the majority of air casualties are due to accidents happening on or near the ground when taking-off or landing, collisions with terrestrial objects in fogs, or through engine failures and by stalling. There have been a great many accidents where no type of parachute at present on the market could have availed the aviators. No existing parachute would have saved Sir John Alcock or Major McCudden, V.C., for example.

It is quite a mistake to suppose that parachutes cannot be used with the machine in any position. They can be so used. The Germans so used them.

What is good for military machines in the matter of life-saving equipment should surely be as useful on passenger aircraft.

So far parachutes have not been made compulsory on any form of civilian aircraft. Until compelled by legislation aerial transport companies are not likely to reduce their useful carrying capacity by the voluntary provision of parachutes. Commercial always over-ride humane considerations until Parliament acts. If aerial transportation could be carried out at about half the cost of railway transport, parachutes would, no doubt, be fitted at once as a commendable refinement to every civil machine, if only on account of the attractive reduction in personal premiums already offered by certain insurance companies where parachutes form part of the equipment.

As soon as insurance companies are convinced that parachutes are a reliable means of life-saving, reduction of premiums should go far towards cost of parachutes. " Wheels and Wings " already quotes a substantial rebate if parachutes are fitted.

At present, seeking for plausible objections, but possibly prompted by motives of economy, it is not infrequently argued that the provision of parachutes would unduly emphasise the potential danger of flying, scare the public and reduce the passenger list—in short, the dividends.

The argument that, in large machines, passengers could not get out in time is as much of an argument against the use of large machines as it is against parachutes, but in any case, the statement is one that cannot be substantiated in the present state of our meagre knowledge on the subject. The other argument that " we will wait and see how they answer on military machines before adopting them on civil aircraft " is, like most " wait and see " arguments, fatuous because, in the first place, the price of procrastination may be hundreds of lives and much public confidence lost where parachutes could have prevented these catastrophes. Secondly, there is no need to " wait and see," for the Germans have already conclusively demonstrated the practicability of the aeroplane parachute.

If we " wait and see " much longer we shall wait long enough to see an aerial " Titanic " disaster. The public, who know nothing of aviation and care less at present, will suddenly wake up to the fact that something should be done to make it safer than it is; through the Press they will learn of the parachute and clamour for it.

The recent disaster to the Centaur Triplane at Hayes, where all six occupants were killed, is a clear case of an accident to a multi-passenger machine where all might have been saved by parachutes. The death at Huntingdon of Captain Sadler, who had often dropped parachutists from his machine, is another recent case where parachutes were urgently needed.

The Handley-Page crash at Golder's Green, a week before Christmas, was a case where the ordinary types of parachutes would have been useless, but no argument against fitting them, whilst the loss of another Handley Page in the Irish Sea during the same week was a potent argument for the policy of equipping trans-oceanic machines with parachutes-cum-lifebelts.

The problem of getting all the occupants out of multi-passenger machines is a very difficult one, but is receiving adequate attention.

Probably the most effective solution at present beyond the paper stage is the individual parachute carried on the passenger's back, but attempts to solve the difficult problem of removing the passengers and cabin *en bloc* seem hopeful.

One inventor, regardless of centres of gravity and pressure, seeks to relegate the passengers to the tail of the machine, which member, like that of certain snakes, can be detached at will and be left behind suspended in the air by a great parachute whilst the engine, wings, and, presumably, the pilot continue their headlong career earthwards.

This contraption reminds us somewhat of the desperate expedients of inventors to produce a folding bicycle. The patent records, especially those of the American office, abound with crude ideas for salving a part or the entire aeroplane by means of a parachute shown generally in the accompanying drawings as of hopelessly inadequate size. Strange to say, of the three or four hundred patents I have examined the vast majority show parachutes so small that the speed of descent would be fatal, and with a single exception, not one of all those patents shows the parachute in flight correctly shaped.

In both practice and theory the suspension cords of a parachute must be at a tangent to the surface of the umbrella portion at their points of attachment to its periphery whilst the parachute is in flight. One would have thought this was obvious, but in not a single drawing I have ever seen has it been shown absolutely correct, which only shows how little of the theory the people who rush into patents really know. This may also account for the enormous number of inadequate parachutes proposed, not to mention the ludicrous attempts to combine parachutes with the aviator's clothing.

It would be very convenient if a parachute the size of an umbrella would reduce one's downward speed to safe limits. Unfortunately, the minimum size of parachute to produce a landing at safe speed under any conditions seems to be about 28ft. diameter, which accounts for one of the principal difficulties in the parachute problem.

In the American patent files there are at least a dozen showing a parachute about three feet across for saving a man. Equally quaint are some of the parachutes shown as salving the whole aeroplane. These vary in the specifications from 10 to 20 feet in diameter and are invariably shown vertically above the centre of gravity of the machine, with the latter horizontal just as if it had no forward speed. To salve a super Handley a parachute the size of Trafalgar Square, weighing a ton or more, would be required.

The first authentic reference to parachutes as they are known to-day is to be found in the aeronautical sketch book of Leonardo da Vinci (A.D. 1500). His prevision was extraordinary. He outlines a parachute almost identical in size and construction with those used for man-saving during the war.

He does not seem to have known quite how it might be used, but as flying was always regarded as inherently dangerous until it was actually achieved in 1908, early investigators often thought more of the cure than the prevention of accidents and Da Vinci was an inventor of flying machines—orthopters.

As to actual descents, there are perfectly credited records of such having been made from a tower in the 18th century by Fauste Veranzio, using a cloth stretched on a rectangular framework. Another experimenter, Gaspard Le Norman, undoubtedly made descents with something of the same kind in 1783. Montgolfier also made a couple of descents.

In 1793 Blanchard, the well known pioneer balloonist, after trying experiments with his dog, himself made a drop at Basle. He seems to have blundered in some way, probably losing his head and dropping almost as soon as the balloon commenced to rise, so that the parachute was not fully open. Anyhow Blanchard broke one of his legs.

Garnerin, Blanchard's rival, followed suit immediately and with greater success. He made many drops in various countries and one of 8,000 feet in London, landing at St. Pancras.

His sister was the first woman to make parachute descents. She made about 40. In 1804 Kuparento, a Pole, succeeded in saving his life by using a parachute. A good many aeronauts lost their lives by neglecting to equip their balloons with parachutes.

Blanchard and Garnerin had several emulators. The parachute established itself as a medium for sensational performances rather than as an aerial life-saving appliance. The reverse is the case to-day.

Except for the universal adoption of the vent hole suggested by the great French astronomer Lalande, as a palliative to stop the violent swinging to which the early parachutes were prone, nothing of importance occurred until 1837 when Mr. Cocking killed himself by testing his huge inverted cone type of parachute. It weighed over 400lbs. and was forty feet in diameter at the top and eight feet at the bottom. The periphery was stiffened with a tubular tin hoop, the collapse of which, a few seconds after the start, was responsible for the fatality.

In any case so monstrous a machine was quite unpractical except as a spectacular apparatus. It acted as a drag on the Great Nassau balloon when it ascended. The sudden release of so great a weight caused the balloon to bound up many thousands of feet. The discharge of gas from the neck nearly asphyxiated the occupants.

Cocking's misadventure, although without practical, other than negative, value, is the most interesting parachute experiment as it was made with a theoretically efficient type. The collapse was due merely to bad workmanship.

Wise, a really splendid American aeronaut, demonstrated the possibility of such parachutes, not with himself but with his dog, as was the custom amongst the early aeronauts. Wise was not, however, lacking in daring for he invented the thrilling stunt of ripping his balloon in mid-air and allowing it to act as a parachute by reason of the envelope collapsing parachute-wise into the net. This can practically always be relied upon to occur when a spherical balloon bursts, provided there is sufficient height and that the neck line is not secured, or if secured can be untied.

When his balloon burst at 1,000 feet shortly after an ascent from Vauxhall Gardens in 1847, Green, a celebrated aeronaut, saved the lives of his four fellow passengers by his presence of mind in untying the neck line.

Captain Dale, at the Crystal Palace in 1892, was less successful, but then his balloon was at only 600 feet; some of you will remember the event. The two other occupants, one his son, survived.

A somewhat similar but safer expedient is to provide the balloon with a valance around its middle and to suspend the car from the periphery of this flounce. This is known as an equatorial parachute. It is a very old idea, having been suggested by Bramicki in 1867, whilst old cuts show it on Blanchard's balloon in 1784.

Why such a simple safeguard has not found greater favour I do not know, unless it is that bursting is considered too rare to need a remedy.

Dozens of patents exist for making flying machines which incorporate the parachute principle.

To many minds it seems that a descending parachute so nearly floats that it would not take much to make it do so. The fallacy is probably merely an optical and psychological illusion. Having no immediate background by which to gauge the speed of a descending parachute, the spectator, in spite of data to the contrary, often goes away with the impression that the man-carrying parachute floats on the air as lightly as its vegetable prototype, the parachute seed of the common dandelion.

The inventive but unscientific observer proceeds to work out a scheme for making the parachute fly, claiming, with pride, that the passenger can laugh at derangements of the flying gear.

Some, realising the futility of making a parachute fly, have contented themselves with taking advantage of its descent to manipulate subsidiary flying gear or to test manual orthopters.

The two most widely known experimenters of this type of machine were De Groof, who dropped from a balloon at Chelsea where he fell 5,000 feet and was killed owing to his wings folding over his head, and La Tour, who actually had flapped about a bit, but was killed at Lee Marshes through sheer bad luck. His apparatus was suspended below a balloon. It seems that the aeronaut lost his head and acted too late for the flying machine to clear some trees. He immediately afterwards tried to land. La Tour was mortally injured by being dragged. He was French and spoke no English, while the aeronaut spoke no French. No interpreter was in the balloon, so co-operation was at a discount.

The parachute is incompatible with the aerofoil as such. Many unscientific people cannot understand why it is that aeroplane wings do not act, or cannot be made to act, as parachutes when a machine falls or stalls.

Well, they do sometimes, but owing to the immense weight in proportion to wing area—as much as 10lbs. to the square foot in modern machines—the speed of descent would be fatal.

A life-saving parachute, 28 feet in diameter, carries half a pound per square foot for an average man of 160lbs. when opened to a diameter of 20ft. This gives a speed of descent of 16 feet per second, 1,000 feet per minute, or approximately 12 miles per hour. A parachute attains its terminal velocity within a second after opening. The momentum of the load is very rapidly absorbed. Any increase in the load or decrease in the area increases the speed. The resistance varies inversely as the square of the speed so that fortunately stout parachutists will find that the normal size life-saving parachute will not bring them down much faster than their lighter brethren.

Owing to her girl companion fainting when about to do a double descent from a balloon, Miss Dolly Sheppard, a pre-war professional parachutist, courageously seized her in her arms and brought her down on her parachute without fatal, though considerable, injuries.

On two occasions during the war, two officers have accidentally descended from their balloons on a single one-man parachute. On one of these occasions the burst balloon as well came down with the two officers on the one parachute. Lieutenants Pape and Jardine, the two observers in question, were somewhat badly injured on landing.

The original Bleriot aeroplanes were so lightly constructed, on account of their tiny 25 h.p. Anzani engines, that there are one or two cases on record where they pancaked down from considerable heights in true parachute fashion and without serious damage to pilot or machine; but these cases are rare owing to the centre of gravity and centre of lift not coinciding.

Thirty feet per second, double ordinary parachute speed, is generally con-

sidered to be the limit of speed at which a human being could strike the earth without serious harm. That is equivalent to jumping off a wall 14 feet high.

For descents on to hard ground the minimum diameter for a parachute as cut at present should be 28 feet. In flight the "fluting" of the periphery reduces the diameter to about 18 to 20 feet, according to the weight of the load.

G. I. Taylor, the mathematician, has designed a wonderful parachute which comes down at its designed diameter without "fluting."

Mr. Herbert Spencer has used a parachute of only sixteen feet in diameter. None but a very experienced parachutist could survive repeatedly the speed at which a 16-foot parachute must descend. A descent into water from any height might be made with impunity with a parachute of only 10 to 12 feet.

For use on all aircraft having a speed of their own and on captive balloons which have, of course, a relative air speed, due to the wind, it is necessary to pack the parachute in some form of container. On free balloons, owing to the fact that there is no relative air speed, the parachute may be hung fully extended in length from the equator of the balloon. This is the usual practice amongst professional parachutists.

The first attempt to pack parachutes was the Spencer "C" type case, evolved at the instigation of Air Commodore Maitland. It was used with success throughout the war on all kite-balloons and on some airships. Owing to the likelihood of the parachute being blown out of this case before the aviator has dropped the full length of the parachute, and the tendency, therefore, for the slack silk of the parachute to get foul of the aeroplane and tear or tangle, the Spencer "C" case is not suitable for use on aeroplanes.

When it was decided, two months before the end of the war, to equip aeroplanes with parachutes, the only one on the market in large quantities was the Guardian Angel A.1 type. There are fifteen types of Guardian Angel parachutes, of which the A.1 and several others are extracted, by the weight of the falling aviator, from cases pendant from the aeroplanes.

The packing is elaborate and takes two or three hours, but as they are issued from the factory ready for use and need no repacking for a couple of years or more, whilst a Spencer and most other parachutes require repacking weekly, this is not a serious objection.

It is disputed by many persons that parachutes of this normal type (termed by Colonel Holt anchored parachutes) are capable of being used when the machine is out of control.

It is often objected that parachutes must foul the machine in a spin. This is not necessarily the case at all. The smallest machines take at least three seconds to make a complete turn when spinning. In three seconds the parachutist is already over a hundred feet below the point in the air from which he started.

If the suspension cord of a normal type parachute container is made sufficiently long, as suggested by Major Mostyn, the container is clear of the machine before the parachute is extracted, whatever the position of the aeroplane may be.

If the suspension cord is long enough it is immaterial whether the aeroplane winds it round the fuselage half a turn or so during the spin.

The propeller is a possible danger, of course, but it is that on the ground if you try to stop it with your head. If the suspension cord gets foul on the propeller it must be instantly severed, but such an occurrence will be rare and no one claims that parachutes will save cent. per cent. of men who use them any more than lifebelts and lifeboats do.

In certain cases the knapsack type parachute (such as the Autochute, Floyd-

Smith and Mears, to mention three prominent systems of this type) may be less prone to fouling the aeroplane, but there is nothing to prove it yet. So far the claims of their inventors rest on conjecture, except perhaps the Mears, which is closely allied to the German Heinecke parachute, the one that has made over 500 drops from aeroplanes on active service.

It is well known that the anchored type of aeroplane parachute has been ripped on the tail skid on two or three occasions. This is due merely to the fact that the suspension cord was too short. If the suspension cord is made long enough the case must be clear of the tail before the parachute is extracted from it. The only reason why this is not done on demonstration work is that it increases the length of free fall. All demonstrators naturally like to reduce this as much as possible.

An efficient shock absorber must be introduced into this line or the kinetic energy of the container, when it comes to the end of the supporting line, might cause the line to break.

It is claimed by other inventors that the parachute stowed in a knapsack on the aviator's back and extracted therefrom when the latter jumps, either by means of a line attached to the aeroplane, as in the Mears and German Heinecke parachutes, or by the miniature pilot parachute, as in the well known Autochute, Floyd-Smith and Broadwick systems, is far less likely to foul the aeroplane than the original anchored type of parachute. Others contend that the pilot parachute is just as likely to be carried by the slipstream into the tail unless operated intelligently (but who ever heard of panic-stricken passengers acting intelligently?)

In spite of the natural objection of pilots to be saddled with a 16lb. knapsack, this type has found a good deal of favour in America.

In quite a number of the American patterns the aviator is required to jump headlong into space and deliberately liberate the parachute by means of pulling a ring or handle on his chest when he considers that he is well clear of the machine.

This particular method of operation does not seem at all suitable for passenger work, as the passengers, if they could be persuaded to jump at all, might either liberate the parachute prematurely in their embarrassment and so cause it to foul the machine, or might fail to operate it altogether.

The pilot parachute idea is sound so long as it is not left to the aviator to extract or release the pilot parachute himself. This must and easily can be done automatically, and not until the aviator is well clear of the machine.

The Mears is a simple and excellent proposition and for multi-passenger machines the best existing solution, because the passengers can quit in any order, through any exit, having nothing to do but jump, and because the operating attachments left behind on the machine cannot possibly foul the passengers who jump last. It also has the advantage that its extraction from its knapsack case can be delayed until the passenger is radially clear of the machine.

In principle it is merely rolled up in the knapsack from which it is extracted and unrolled by a long flat strip which is attached by one end to the aeroplane and rolled up, as to the other end, with the parachute.

It is these strips which, after the passengers have jumped, remain attached to the machine and blow harmlessly to the rear.

There is one other kind of aeroplane parachute, the extraction type, often termed soaring parachutes, though the impossibility of a parachute actually soaring over a fast moving aeroplane must be apparent to everyone.

The idea is quite ideal and in spite of what has just been said is not absolutely impossible. The attention of inventors should be concentrated on this difficult problem.

Experiment alone can prove whether the parachute thrown up above the machine would exert a pull sufficient to lift the aviator from his seat, before the axis of the parachute, and consequently its pull, was in line with or parallel with the line of flight of the machine.

As the line of flight forms so small an angle with the axis of the fuselage in modern machines the successful operation of the extracting parachute can be decided only by practical tests.

In any case the parachute, however it may be projected above the machine, must lose its forward momentum almost simultaneously with the commencement of its development. Before it is fully open it is bound to travel rearward through an arc having the parachute's point of attachment to the machine or aviator as its centre. It is doubtful whether it can develop sufficiently to exert a pull strong enough to extract the aviator from his seat until it has the pull in a direction which imperils the aviator by collision with the tail of the machine, especially the stabilising fin and rudder.

If a machine is stalling or falling its axis may be at a sufficient angle to the line of flight to obviate the danger of decapitation by the rudder, etc.

Whether the aviator could survive the shock of being whisked out of the machine is a little problematical. In the normal type parachute the strain of having one's momentum arrested, even after a fall of several hundred feet, involving a speed of 95 m.p.h. after a fall of 300ft. or more, is almost negligible. There seems therefore no reason why the actual act of extraction should in itself prove fatal. At the same time it does not matter whether the aviator is dragged out of the machine in his seat or by means of body harness, the strain of his transmission ultimately falls upon him.

It may be that the cone of air set up by the slipstream would cause the parachute to the function at an angle of 10 degrees or so to the axis of the machine, and it may be that the steeper the machine was diving the more the action of this type of parachute would be favoured. Rollers on the back of the occupant's seat to lift him, seat and all, with an initial trajectory sufficient to clear the empenage have been suggested by Haydn amongst others.

Pégoud did actually succeed in getting clear from a 25 h.p. Bleriot machine single-handed with a parachute of this kind invented by a canteen keeper called Bonnet. It was operated by means of a pilot parachute. It is interesting to note that the first drop ever made from an aeroplane in Europe was operated by the pilot-parachute system. Pégoud's machine, continuing on a mad career by itself, looped the loop, which suggested to him the possibility of his doing likewise. It finally landed almost intact.

A third essay by Pégoud's pupils Lemoine and Bourhis for a fee of £1,000 at Vienna nearly proved fatal. Everything went wrong. Part of the metal sheath which covered the parachute fouled and damaged the empanage and elevators. Lemoine, the pilot, crashed and was in hospital for three months, whilst Le Bourhis, the parachutist, came down at almost fatal speed on half a parachute and broke his leg.

The very first man to drop from an aeroplane by parachute was an American named Berry at St. Louis in America, just 12 months in advance of Pégoud; the first man in England, Professor Newall, the first woman, Miss Broadwick, in America, and Miss Sylva Boyden in England, who has since done much to prove that parachuting is not dangerous.

The path taken by a parachute is rather interesting. Instinctively one thinks that a parachute drawn out from a container below a flying aeroplane will describe a rearward and downward path in a straight line at an angle of about 45 degrees to the aeroplane. A little further consideration confirmed by photographs shows that the exact opposite is the case.

Parachutes do not conveniently slow up like lifts on reaching the ground. The landing is often much more severe than is generally supposed, especially in a high wind, as the parachute has the speed of the wind in a horizontal direction over the ground. In a wind of 30 miles per hour one might just as well jump off the roof of a closed motor car going at that speed. On October 3rd last year, Miss Boyden established what is easily a record for contempt of danger by jumping from a machine when the wind was 90 miles an hour in the air and 60 miles an hour on the ground. She jumped at 300 metres, drifted 2,800 metres, using a 28ft. parachute. She luckily landed in a marsh almost unhurt, but narrowly escaped drowning. She might just as well have jumped out of the Holyhead express going at full speed.

Swinging, which often occurs during the descent, may cause the aviator to land heavily on his back or even head.

Within narrow limits, a parachute may be guided if the passenger is within reach of the rigging lines, but owing to the length of life-line necessary to connect the aviator to his parachute, in some types of aeroplane parachutes the means of dirigibility are usually beyond his reach.

For military use devices for reducing the effective area by peripheral contraction of the mouth or otherwise so that the speed can be greatly increased in order to avoid the attentions of an aerial enemy who persists in amusing himself by firing at the parachutist, may be useful.

It is quite a general opinion to suppose that parachutes frequently fail to open. That opinion is wholly fallacious. During the war the ordinary parachute stuffed, more or less anyhow, into the Spencer C. case only failed to open once in every two hundred times. Failure to open is due to the fact that the rapid descent of the parachute converts the vent-hole at the apex into an air ejector; a vacuum is thus formed inside the parachute.

The vacuum causes the sides to stick together and so tends to keep the mouth closed. In 199 cases out of 200 air enters at the folds of the mouth and, overcoming the vacuum, inflates and develops the parachute. In the Autochute this tendency is ingeniously and simply overcome by inserting a sheet of paper inside the vent hole of the parachute, thus preventing the formation of a vacuum there. If it has not already done so before, the paper bursts as soon as the parachute is fully open and has taken up its load.

In the French Ors parachute, the American Folmer Clogg and the English Blackburn, Salvus and Guardian Angel, the mouth of the parachute is automatically and positively opened as the parachute leaves its container. This makes failure to open impossible. Positive opening is a vital necessity on all parachutes. Without it there is no certainty how soon the parachute will open or whether it will open at all. Anyone will agree that unless you can rely upon a parachute opening before it has fallen, say, 150 feet, the parachute is practically useless for aeroplane work, where so many of the accidents and derangements occur near the ground. It is equally important that the parachute should not open too soon or it may get foul of the falling machine. The ideal parachute must do the same thing in the same way in the same time, time after time. It ought to be possible to arrange or predict with precision the exact distance the aviator will fall before the parachute opens. With equal speeds and weights the depth of free fall must be a constant.

Next in importance to positive opening is positive extension, that is, the extension lengthwise ought to be effected by some positive reaction and not merely by air friction or inflation of the parachute.

The more positive and the better controlled these operations are, the more reliably will the parachute function.

During the war, quite five per cent. of parachutes emerged from their cases

with tangled rigging lines. In several cases the tangles were so close up to the parachute that the mouth only partially opened, the terminal velocity was excessive, and the aviators were severely injured. Tangling can be obviated only by making the rigging lines tangle-proof; this has been done by one maker. It is an indispensable safeguard and should be universally adopted. It is not difficult to do.

To be entirely practical, a parachute must be installed in an aeroplane so that it can be automatically delivered to either side of the machine when the machine is in any position. The system of installation necessarily differs with the different types of machines.

In single and two-seaters, the parachutes, if not of the knapsack type, are usually installed in compartments in the fuselage from underneath which they issue automatically on the fall of the aviator, or in the top fairing, whence they are ejected by means of catapults operated automatically.

By far the greatest danger of parachuting is landing. One may land on a house, on live wires, or in front of a train. If there is a strong wind blowing, the aviator is dragged along the ground, and seriously injured or killed, by the parachute acting as a sail.

The power of a parachute impelled by the wind is incredible. Six strong men are helpless to hold it in only a 30-mile an hour wind.

A sharp knife is often supplied for the purpose of severing the life-line on landing, but it is just as often forgotten at the moment of jumping or lost on landing. The only real safeguard is some form of quick release, of which there are very many patterns. The quick release must be proof against tampering on the way down, and against premature operation, or it will kill more than it will save.

The most dangerous predicament is to land on the roof of a building in a wind. Nothing but an instantaneous release and prompt action will prevent the parachutist from being dragged off by his parachute and killed. Viola, a professional lady parachutist, was killed in this way at Coventry in 1911. She landed on the roof of the Centaur Cycle Works.

Demonstration drops from aeroplanes are usually made by experienced parachutists under the most favourable conditions from machines flying on an even keel over safe ground. The demonstrators do not, as a rule, trust themselves to quick releases, but if a wind is blowing they take care to extricate themselves from their harness shortly before reaching the ground.

The unreality of demonstration drops has often been criticised as forming no criterion as to what would happen and how people would act in an aerial emergency. Opinions naturally differ widely on this conjectural point. It is said that the passengers would not, and often could not, quit the machine. It is, however, merely a question of incentive and of personal selection.

In cases of fire in the air, happily rare, but not yet entirely extinct, people would jump without thinking twice. There is always the reflection that if you jump you may be killed, but if you remain in the machine you are certain to be.

Panic will seize air passengers, just as it seizes people in earthquakes, shipwrecks, etc., but those that keep their heads will make use of their parachutes if in their discretion it is imperative to do so.

The saving of passengers by parachute from multi-passenger machines is the biggest problem that the parachute expert has to solve. A solution has just been patented in which one huge parachute has been designed to lift from the aeroplane the cabin complete with its human contents, even at a few feet from the ground. The decision and operation are placed in the hands of the pilot.

The invention needs trying out and development. Its principal advantage is that the passengers are not called upon to think for themselves.

To assert, as is often done, that aerial accidents can be totally eliminated, is most pernicious, however bona fide that opinion may be in the minds of the people who state it. Aerial accidents can be eliminated no more than railway accidents, shipwrecks, and thunderstorms, in all of which every possible safeguard is provided. Life-saving equipment is only one of the safeguards. In no kind of transit is reliance placed wholly on life-saving gear to the exclusion of all other precautions, nor is life-saving gear expected to save more than a percentage of the passengers. The most ardent enthusiast does not claim that parachutes will save more than fifty per cent. of passengers, because you cannot expect stout gentlemen and old ladies to act with the experienced agility of German pilots, whose escapes at present provide the only available statistics of life-saving from aeroplanes, nor will parachutes save passengers in taking-off and landing crashes.

DISCUSSION.

Sir SEFTON BRANCKER said he had felt like a prisoner at the bar when he heard the criticisms the lecturer made as to the value parachutes might have had during the war. He had said that they could have saved 5,000 people, or something like that. He could not remember exactly why the use of the parachute had not developed more quickly. They were used in 1917 for dropping spies with very good success. He thought the delay in the development of the parachute was chiefly that the people in the field did not ask for them as they did not think they would be necessary nor successful. But when Major Orde Lees came to him in 1918 he was an absolute godsend and through his energy and enthusiasm they pushed the parachute on and got it ready in August of that year. He was very strongly in favour of the use of parachutes for war purposes. Their use covered three classes of accident—(1) fire, brought about by incendiary or explosive bullets; (2) breakage of the machine in the air, brought about by shell or machine gun fire; and (3) collision, which would be more frequent in the future in the aerial battle or "dog fight." But when they came to commercial aviation he implored the lecturer to go easy. They must take care not to rush into panicky legislation, insisting on the use of parachutes in all commercial aircraft. The task of making commercial aviation pay was already a difficult one. The lecturer talked about dividends, but no one had any dividends yet, and it would be some time before they had any. The provision of parachutes meant additional expense, additional weight and valuable space being taken up; and also in the present state of affairs, when passenger-carrying machines were usually limited by economical conditions to a small eight-passenger machine it would be difficult for the passengers to save themselves on parachutes. To deal with the three classes of accidents he had mentioned—(1) fire, well they must not allow fire in the air, there was no reason why there should be any; (2) breakage in the air was equally inexcusable; and (3) collision might come eventually, but it would take rather a clever man to collide with British machines at present! It was a curious thing that parachutes were never discovered in Zeppelins during the war. Perhaps the Germans were afraid the men would jump out in England and be prisoners rather than go back to Germany. He was glad to hear the lecturer say a soaring type of parachute had a chance of being a practical proposition. When he (Sir S. Brancker) first saw it on paper he was very keen on it. The scientists said, however, it would not only break the tail but would break the pilot's neck in pulling him out. The latest event in the development of parachutes during the last few months was when one of the starters in the Gordon-Bennett race—an American he believed—came over to France to fly a light fast machine from which he intended to drop

the undercarriage to get speed, and, having passed the winning post, was going to jump out and let the machine go as he would not dare land it. He concluded by saying that the lecturer was perhaps the bravest and one of the most enthusiastic men he had ever met.

(*Note sent to Secretary afterwards.*) I omitted to point out that in no accident which had occurred to a British commercial aircraft running on a regular air service during the last two years would the provision of parachutes have been the least use. When increase of traffic and frequent night and cloud flying make collisions possible, then parachutes must be provided.

Major G. I. TAYLOR said he supposed he had been asked to speak because some time ago he designed the shape of a parachute, which he now exhibited, and which did away with all those crinkles which were rather a disadvantage. It would be seen from the model that two pieces of stuff were stuck together and on blowing it up it got to a certain shape and looked absolutely stiff. It looked like two parachutes put together.

The number of occasions on which a scientific man, or a man who had done a good deal of observation, had done parachute descents from an aeroplane was comparatively small. He made one about three weeks ago. When he heard Major Orde Lees was coming to Cambridge to give a demonstration, he (Major Taylor) thought it was a good opportunity to try a new experience, so he asked Major Orde Lees to bring a spare parachute with him. The first thing he (Major Taylor) noticed after successfully clearing the control wires by means of a vigorous jump outwards was that the small strain exerted on the rope to which he was attached by the pull of the parachute in coming out of its case was sufficient to turn him upside down into a position which was comfortable for observing the parachute open. The strain of opening was quite small owing, presumably, to the design of the harness, though of course he had his forward speed of 60 miles an hour or so as well as the vertical speed due to a drop of 60 or 70 feet.

When the parachute opened the sensation of floating gently downwards was extremely pleasant, but on approaching the earth he found himself going backwards over the ground. In order not to be dragged backwards along the ground on landing it was necessary to turn so as to face down-wind. It is impossible to get any grip on a vertical string from which one is hanging so as to produce any tendency to spin one round. The problem is exactly the same as that of turning on a music stool when one cannot reach the ground with one's legs. It is also the same as that of a cat which can turn so as to fall on its feet when dropped upside down a few feet from the ground. In this case he (Major Taylor) solved the difficulty by putting his legs out, swinging them round into the wind so that the reaction swung his body round till it faced down-wind. He then brought his legs straight back under his body and found himself in the correct position for landing.

The landing itself was carried out with about the same impact as that one gets when jumping off a motor bus going at a moderate speed. After touching the ground he immediately ran forward so as to release the pressure of the wind in the parachute as it blew forward into a horizontal position. The parachute then collapsed in a perfect circle on the ground.

Parachuting can be recommended to those who like new sensations as a sport on which it is well worth while to spend a fine summer afternoon.

Major Orde Lees then gave a demonstration of the opening and dropping of a full-sized parachute which had been suspended from the ceiling of the hall.

The CHAIRMAN expressed the thanks of the Society to the author, who, he said, would reply to the discussion in writing.

CONTRIBUTED.

Major Orde Lees is to be congratulated upon the production of a paper of considerable interest to those who have concerned themselves with the question of providing means whereby aircraft personnel may be given an avenue of safety in the event of disaster whilst in the air.

The parachute has been, not inaptly, termed the "lifebuoy of the air," and whilst under a disadvantage with respect to its marine counterpart in the small space of time within which it must be brought into operation, it has the advantage of bringing its passenger safely to terra firma, whereas an ordinary lifebuoy is only useful in conjunction with boats or other auxiliary assistance.

The figures quoted by the author as to the number of German pilots saved from damaged machines during the latter phase of the war are very remarkable, and if, as he suggested, they could be officially authenticated the value of aeroplane parachutes would be placed in an unassailable position.

I should like to correct what appeared to be a serious error made by the author in his attempted classification of types of parachutes. From his remarks it would be inferred that with the "Salvus" parachute it was necessary for the passenger to perform certain operations *after* jumping from the aeroplane, whereas this parachute is entirely automatic and, as a long series of trials have demonstrated, embodies four fundamental requirements of a satisfactory aerial life-saving device, viz. :—

(1) *Automatic Action.*—So that the passenger has to perform no other act than to leap or fall from the machine.

(2) *Instant Detachment.*—So as to avoid fouling the tail skid or other part of the machine in the case of a spinning dive.

(3) *Positive Opening.*—To ensure the functioning of the apparatus within a short and known length of fall.

(4) *Small Shock of Opening.*—To provide for comfort of the passenger and avoid undue stresses in the apparatus without the use of springs, dashpots, or other shock-absorbing devices.

With respect to the risk of parachutes fouling the aeroplane when used from a machine in a spinning nose dive, there is, of course, no likelihood of the parachute being wound up like string round a peg-top as some people imagine. But the author appears to dismiss the real risk far more airily than is justified if careful consideration is given to the time-sequence involved in such a manœuvre.

A parachute when extended to full length measures about fifty feet from apex of silk body to passenger, and types that require to be fully extended before finally leaving the container require about one and a quarter seconds from the time the passenger leaves the machine before they become fully detached when used from an aeroplane flying level.

If the machine is diving, the relative acceleration between machine and passenger is reduced to less than $g = 32$ with a corresponding increase in the time required for detachment, which may reach three to four seconds.

Apparatus of this slow-detachment type is quite suitable for leaving a machine that is flying level under control providing adequate precautions are taken to prevent the silk body being damaged by the tail skid.

But many machines when spinning have a period of spin from three to four seconds, so that in one second or less the rearplane will be standing at 90 degrees to its position when the passenger left the machine and practically form a tail skid some eight feet long threatening the delicate fabric of the silk body.

One method of attempting to overcome the above difficulty, as mentioned by the author, is to drop the entire parachute in its case on the end of a rope.

An objection to this is that the mass of the parachute (probably about 20lbs.) moving with the velocity due to a fall of many feet and accentuated by the action of the slip stream, has to be suddenly checked with a considerable resultant shock which synchronising with the effort of opening the container may entail very heavy stresses on the connections to the aeroplane with possibilities of breakage, or necessitating the addition of special shock-absorbing apparatus.

The author mentions the possible evolution of a parachute designed to rise above the fuselage and lift from the machine the entire cabin complete with passengers, and if this scheme can be satisfactorily worked out in a simple and practical manner it should offer considerable possibilities for civil aviation by overcoming the difficulty of getting a number of untrained persons away from the aircraft with sufficient celerity.

ERNEST E. SMITH.

LECTURER'S REPLY.

When Sir Sefton Brancker says he feels like a prisoner at the bar, I hasten to re-assure him that, though I admire his customary magnanimity in taking on his own broad shoulders the responsibility for not having adopted the aeroplane parachute earlier in the war, my indictments were entirely impersonal and so far from his being an obstructionist in the matter he was the first and the readiest to appreciate the life-saving potentialities of the aeroplane parachute.

As Sir Sefton says that these parachutes were got ready in August, 1918, it really is a scandal that not a single Air Force pilot has ever yet flown on a machine with a parachute fitted to it as standard except experimental machines after a lapse of over two and a half years.

It is all very well to say that accidents of various kinds are inexcusable, but you cannot entirely eliminate aerial accidents any more than you can railway smashes, shipwrecks, or thunderstorms, where every precaution is taken to save life.

The question of cost is a hard one to face, but conceive the public outcry if lifeboats were removed from ships because they cost too much. No price is too great to pay when human lives can be saved. It is an argument that was used by the R.A.F. in April, 1919, and one which I will violently oppose as long as my pen holds ink. I do not see why legislation on the point need be panicky.

The question of weight and bulk and consequent reduction of carrying and earning capacity is merely a question of urgency. Lavatories are so much waste space and passengers are often too bashful to use them; still they are considered necessities.

It is difficult for passengers to save themselves with individual parachutes, but desperate men make desperate efforts, and Sir Sefton does not use the word impossible, indeed, he goes so far as to say that he is in favour of the use of parachutes *for war purposes*. I do not think he makes at all a good case for the distinction between war purposes and travel purposes.

I think the reason given by Sir Sefton for the absence of parachutes in "Zepps" is the right one. I have been told that they were removed at Ostend. When the Germans began to use parachutes in aeroplanes an unscientific observer reported that their parachute was lifting the pilot out of the falling machine. Am I not right in saying that Sir Sefton was influenced by this report, which I was certain at the time, and have since proved, was an unintentional misrepresentation.

I should like to shake hands with the Gordon-Bennett Yank who proposed dropping his undercarriage and later himself by parachute. I should like to

subscribe to the final obsequies of the people who helped to stop the under-carriage and the aeroplane after our friend had no further need of them!

I have always regarded Major Taylor with reverent awe as the arch-figure-juggler of aviation. How a man can design a floppy thing like a parachute mathematically, and get it right, too, is quite beyond my limited comprehension. But when such a man comes and does an ordinary parachute descent he seems to come off his pedestal down to the earthly plane once more on a level with myself.

Major Taylor's contribution is a very wonderful parachute which, for its weight and area, has a much lower terminal velocity than any other parachute. In it he has eliminated the inefficiency due to "fluting" at the periphery.

T. ORDE LEES.

The CHAIRMAN said before calling upon Mr. J. W. W. Dyer to read his Paper on "Airship Fabrics" he would like to tell those present a few things about him. Before joining the Airship Service in 1915, Mr. Dyer was the author of several works on the chemistry of cellulose. He joined the Airship Service in 1915 at Kingsnorth and became assistant chemist at that establishment, where he worked mainly on the determination of the permeability of airship fabrics, and the circumstances which governed the loss of gas-tightness and loss of strength in those fabrics. Since the end of 1918 he had been chief chemist, and had been engaged on important airship research work. During the last nine months he had been directing experiments of exceptional importance in exposing various gas-bag and outer cover fabrics to the tropical conditions of Egypt. A large proportion of those gasbags and outer cover fabrics had just come back from Egypt, and Mr. Dyer was now studying them closely and reporting officially on them. So he thought it would be seen that Mr. Dyer could speak with great authority on his subject.

Mr. J. W. W. DYER then delivered the following lecture :—

AIRSHIP FABRICS.

A proper treatment of the construction and properties of airship fabrics would require a book rather than an essay. In what follows, it is possible therefore to deal briefly only with the principal types of fabrics, classified according to the main functions of each, describing their structure and behaviour and the chief factors affecting their permanence when in service.

There are, then three main classes :—

I. Fabrics for the envelopes of non-rigid airships.
II. Fabrics for the gasbags of rigid airships.
III. Fabrics for the outer covers of rigid airships.

In all cases low specific weight (expressed here in grammes per square metre*) is clearly of the greatest importance.

I. Fabrics of this class must possess gas-holding properties, mechanical strength and pliability. The internal pressure (equal to about 30mms. of water) which maintains the shape of the envelope sets up in its fabric considerable tension, and this is increased by the distributed weight of the whole ship.

Non-rigid envelope fabrics are normally of rubber-proofed cotton. The number and weights of the plies of cotton and the total weight and distribution of the rubber depend on the precise purpose for which the fabric is intended.

Some typical fabrics may be illustrated by reference to standard British practice. Cotton cloths are used having the weights and tensile strengths given in the following table :—

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† gms/m² ÷ 34 = ozs.yd² correct to about 1%.

Reference letter.	Weight gms./m².	Strength kgs./m.
B	110	1100
C	80	800
D	65	650
E	45	510

It will be observed that all have nearly the same specific strength or a common breaking length† of about 10,000 metres. Cotton is used in preference to linen largely because its greater uniformity and smoothness make it more suitable material for the proofer. Single-ply fabrics are not used for several reasons. In the first place, local defects might cause serious weakness; secondly, they have little resistance to tearing when wounded; thirdly, a sufficient weight of rubber proofing of proper quality placed between two cotton plies gives greater gas-tightness than the same weight and quality used as facing of a single ply. In two and three-ply fabrics the plies are held together by the rubber proofing which is also the gas retaining member of the compound fabric. On the outer cotton face is placed either camouflage colouring or a layer protective against the weather or an attempt to combine the two. Typically the protecting layer is of a special rubber proofing having a surface of aluminium powder printed on it. The following schemes represent normal two and three-ply fabrics such as are used respectively for small non-rigids and for the top lobes of large trilobe non-rigids. The letters represent cottons of the above standard types.

Two-Ply.	Three-Ply.
B	C
Main gas holding rubber, 100 gms./m².	Main gas holding rubber, 100 gms./m².
(C)	(C)
Outer protective rubber-aluminium layer, 50 gms./m².	Rubber layer, 30 gms./m².
	C
	Outer protective rubber-aluminium layer, 50 gms./m².
Total Weight, 340 gms./m².	Total Weight, 420 gms./m².

The letters in brackets ( ) indicate a ply laid with its yarns at 45 degrees to those of the other ply or plies, *i.e.*, diagonally or on the bias. This greatly increases resistance to tearing and is discussed more fully below. It may be stated here that rubber is chosen as proofing material not because, for a given weight, it has the lowest permeability to gases of all readily accessible plastic materials, but because other media which may be excellent for low permeability have disadvantages of one sort or another from which rubber is free. Gold-beaters skin, oil proofing, gelatine proofing are all excellent for gas-tightness, but expense, fragility, slow production of the first, defective strength and difficulty of seaming of the second, and in the case of gelatine dependence for useful life on retention of moisture not possible in hot dry climates, are reasons (among others) why these substances as at present applied are inferior to rubber for the purpose of non-rigid envelope construction.

It will be convenient to treat the tensile, gas-holding and weathering properties of rubber-proofed fabrics in separate sections.

(*a*) *Tensile properties.*—The standard cotton fabrics of the table already given will be regarded as the basic materials having the strengths there stated, and this section will discuss the strengths of balloon fabrics, built up from them, when tested in various ways.

The simple tensile strength is normally measured on a piece of 5 cms. width and about 20 cms. (effective) length. The ends of this test piece being secured in suitable clamps, it is then treated so as either

† *i.e.*, a length which would break under its own weight, often a useful basis of comparison.

(*a*) To stretch it at a constant rate, or

(*b*) To increase the load on it at a constant rate till it breaks.

The second, the constant rate of loading test, is the one usually employed in experimental work and now insisted on in contractual testing, and all tensile tests discussed here have been made in that way. A figure purporting to give the strength of a cotton fabric is highly arbitrary. This will appear more fully from what follows, but it may be stated here that it depends on the kind of machine used ((a) or (b) above), the humidity conditions of the fabric, and this, if equilibrium has been reached, depends on the temperature[1] and humidity of the ambient air. Further, the apparent strength depends on the rate of applying the load during the test. The higher the humidity and the faster the rate of loading, the greater is the apparent strength.[2]

When in use, the fabric is under compound stress and it is clearly desirable to be able to predict its behaviour in such conditions from the simplest tests on small pieces. The range of data available is not such as to make this possible for all two or three-ply fabric combinations that might be selected, but a good deal is known with reference to certain much-used types. The points of interest are obviously :—

(i.) The strength of the two and three-ply fabrics in simple tension and the relation of this to the strengths of the component cloths.

(ii.) The strength of wounded fabrics.

(iii.) The relation between simple tensile strength and the result of various compound stress tests including bursting.

(iv.) The effect of a sustained load.

(i.) In tabular form below are given the strengths in simple tension of a number of two-ply fabrics. Their structures are indicated by letters signifying standard cottons from Table I. Letters in brackets signify bias ply. All results are in kilos/metre.

T = strength of compound fabric.

t_1 and t_2 = strengths of component plies, t_2 being used for the bias ply. The t_2 of columns 6 and 7 is the mean of the warp and weft values.

Figures in brackets denote strengths as specified in Table I. and not actually found by testing the separated plies.

1. Structure of fabric.	2. Direction. tested.	3. Kilos. T.	4. per t_1	5. Metre. t_2	6. $\frac{T}{t_1\ t_2}$	7. $\frac{t_2}{t_1\ t_1}$
A (D)	Warp	1560	(1250)	(650)	.82	.66
B (C)	Warp	1306	(1100)	(800)	.69	.56
B (C)	Warp	1183	980	626	.75	.62
	Weft	1234	1080	580	.73	.64
C (C)	Warp	1025	800	844	.64	.50
	Weft	932	653	753	.64	.45
D (D)	Warp	742	635	553	.60	.56
	Weft	707	562	463	.58	.53
BX (BX) ...	Warp	1000	625	852	.69	.43
	Weft	1000	635	800	.69	.43
CC Parallel ...	Warp	1705	(800)	(800)	1.06	.5
	Weft	1580	(800)	(800)	.99	.5

[1] The distribution of moisture between the air and the cotton depends on the temperature.

[2] It would appear that the different results given by different types of testing machine should be explicable on this ground. The writer has, however, data which conflict with this view, but they cannot be discussed here. It is doubtful whether comparisons under carefully controlled or observed conditions have been made.

It will be observed that there is a variable difference between the numbers in columns 6 and 7, this difference being related to the support in simple tension given to the straight ply by the biassed. A direct tension test on a diagonally doubled fabric is of course somewhat unreal and unrelated to the conditions obtaining in actual service. It is a rough guide only, and the above figures are to be regarded as fairly typical while not serving for the deduction of any rule applicable to all bias doubled fabrics.

(ii.) Resistance to tearing, *i.e.*, to the indefinite extension of a small wound, is very important for non-rigid envelope fabric. It is a property conferred on the fabric by the presence of the bias ply, whose marked influence in this respect is shown by the figures given in Table III. Tearing or wound strength is given for an initially wounded test piece by the expression

$$\frac{\text{Load to produce tearing}}{\text{Width of test piece.}}$$

Provided the test piece is large enough to include the area of non-uniform stress distribution[1] caused by the presence of the wound in the stressed specimen, the value of this expression is independent of the width of the test piece and for a given form and size of wound is a characteristic of the fabric. In Table III. it is expressed as a percentage of the strength of the unwounded material. The results relate to test pieces 6in. wide by 20in. effective length having transverse central cuts. The column headed b/s gives the ratio

$$\frac{\text{Strength of bias ply (or plies)}}{\text{Strength of straight ply,}}$$

and the percentage wound strength is seen to increase with increase in this ratio.

Further reference to factors affecting tearing strength is made in a later section on weathering.

Fabric.	Tearing strength as percentage of full strength. $\frac{1}{2}$" cut.	1" cut.	$1\frac{1}{2}$" cut.	b/s
1-ply proofed C	40	22	19	—
CC parallel	33	24	18	—
Plain 1-ply linen (130 gms./m^2	52	41	33	—
B (D)	57	46	41	·59
B (C)	62	45	—	·73
C (C)	72	59	51	1.0
D (B)	79	69	63	1.7
C (C) C	50	35	—	·5
CC (C)	88	—	—	2.0

(iii.) The behaviour of fabrics both unwounded and wounded under compound stress conditions has been studied in three principal ways :—

(*a*) By loading the arms of a cross-shaped piece the central square is placed under compound stress, the ratio of the two stresses being variable at will. There are, however, few results by this method, particularly on biassed fabrics. It has the disadvantage that the stress on the test square is different by an unknown amount from that calculated as the quotient of the load by the width, on account of enhanced stresses which exist at the corners of the square.

[1] The so-called " danger rectangle."

(*b*) Small cylinders of fabric 5in. diameter and 30in. long having metal end pieces have been used. They were subjected either to pressure above or to pressure plus further longitudinal tension by loading them as they were held in position between the grips of a fabric testing machine. In other cases, using similar cylinders bursting pressure only was applied with no additional longitudinal tension. From tests of this nature with small cylinders the values for the ratio

$$\frac{\text{Tensile strength by bursting}}{\text{Simple tensile strength}} \text{ or } \frac{T_b}{T_t}$$

were found to be 1.4 to 1.6 for various biassed fabrics, 0.6 to 1.6 for parallel doubled and about 0.7 for single ply.

(But see succeeding section.)

(*c*) Bursting tests on larger models.

Larger cylinders ranging up to about $3\frac{1}{2}$ metres diameter and having hemispherical ends have been used by Avorio in a number of bursting experiments. He found a scale effect with cylinders up to one metre diameter such that the bursting stress decreased with increasing diameter. Beyond this up to the largest tested there was no further decrease. From the minimum results, his values for the ratio T_b/T_t were found to be 0.63 and 1.00 for parallel and diagonal two-ply fabrics respectively.

In some tests carried out a year or two ago in this country, models 20 feet long of the SS. type of non-rigid airship were used. The envelope except for one gore was of strong three-ply fabric. Gores of the experimental two-ply fabrics filled the gap, in turn being inserted by stuck seams. Pressure was supplied by means of a blower, the circumference at burst and bursting pressure was measured. Such tests were made on whole and variously wounded fabrics of three types, the wounds being made at the maximum diameter before the pressure was applied. The weft yarns took the hoop tension and there were no transverse seams. For comparison with the results of these experiments the weft strength of the fabrics in simple tension, both unwounded and wounded, were also found.

Table IV. gives the results (T_b for bursting tests, T_t for tensile tests) in kilos/metre.

Table V. gives the ratio T_b/T_t for several of the conditions tried.

TABLE IV.

Fabric.	T_b Kilos/metre.				T_t Kilos/metre.			
	No. wound.	$\frac{1}{2}$" hole.	$\frac{3}{4}$" hole.	$\frac{3}{4}$" slit.	No. wound.	$\frac{1}{2}$" hole.	$\frac{3}{4}$" hole.	$\frac{3}{4}$" slit.
C (C)	1110	1115	1007	825	996	707	650	620
B (D)... ...	1366	1004	920	—	1140	715	664	620
CC Parallel ...	1130	513	435	340	1250	604	500	423

TABLE V.

Fabric.	Ratio T_b/T_t.			
	No. wound.	$\frac{1}{2}$" hole.	$\frac{3}{4}$" hole.	$\frac{3}{4}$" slit.
B (D)	1.20	1.40	1.38	—
CC Parallel ...	.90	.85	.87	.80
C (C)	1.11	1.58	1.55	1.33

The cottons in the three fabrics were not exactly of the weights specified in Table I. Actually the total weight of cotton was, within a very few grams per square metre, the same in each fabric. The strength figures as they stand are therefore proportional to specific strength. The results show the superiority of diagonal over parallel fabric and also how misleading, for this comparison, a simple tensile test is. The C (C) fabric has for small wounds a slight superiority over the B (D), but there is an indication that with larger ones this might disappear. The results of Table V. stand between Avorio's and those quoted in section (*b*) above. Comparative bursting and tensile tests do not seem to have been made under strictly comparable or observed conditions. Scale effect, seams, humidity, temperature and rate of loading all affect the comparison. Rate of loading affects the apparent strength of two-ply fabrics very considerably. Corresponding to rates of 30lbs./in/min. and 150lbs./in/min. differences in apparent strength of the order of 10 per cent. and 20 per cent. for two-ply diagonal and parallel respectively may be found, the higher rate giving the greater apparent strength. This is for unwounded test pieces. The rate of rise of pressure was not taken in the bursting tests described above but they probably correspond to a rate of loading slower if anything than the slower of the two just quoted. The tensile tests compared with them were made at the slow rate. Had they been at the higher rate the tensile figures would have been higher and the ratio Tb/Tt correspondingly reduced.

Strength Under Sustained Load.

IV. This is of the greatest importance, but only comparatively lately has it received attention. Work on the subject is at present in progress. The data now available from earlier work are not numerous nor readily summarised in a general statement. The figures in Tables VI. and VII. will give an idea of the behaviour of fabrics under conditions of sustained load.

TABLE VI.

Tests on warp direction of B cotton. Normal breaking load at 72 per cent. humidity and 150lbs./in/min. loading = 129lbs./2".

Load applied.	% of Normal Breaking Load.	Time to break.
116	90	1 or 2 seconds.
110	85	A few seconds.
103	80	8 to 13 minutes.
95	75	1 to 2 hours.

TABLE VII.

Fabric.	Kilos/metre.		% of normal	
	Normal strength.	Sustained load.	breaking load.	Time to break (days).
C (C) C warp	1900	950	50	5
B D Parallel warp	1460	900	62	5
B (D) warp	1310	680	52	7
Single-ply linen 120 gms./m^2	1100	620	56	5

The fabric is not seriously weakened as a whole by sustained loading. If after the break the remaining portions be tested in the ordinary way they are found to have a strength little lower than that of new material. This behaviour of

fabrics under sustained load is clearly of great importance and introduces a new corrective to the estimates made of the stength of the fabric as compared to the stresses it is subject to in service.

The Fabric as a Gas Holder.

The two and three-ply fabrics, whose structure is described in an earlier paragraph, each contain a layer of rubber proofing of 100gms./m². It is on this principally that their gas-retaining properties depend, and in present-day fabrics a proofing layer of 100 to 120 gms. specific weight is adopted, the lower figure being the normal standard. In the three-ply fabric the second layer between plies of 30gms./m² is merely to hold the middle and outer plies of cotton together, though it will undoubtedly help to reduce the permeability of the fabric. The outer layer of 50gms./m² also helps when the fabric is new, but in use it probably ceases to function as a gas holder after a very short time while still remaining a more or less efficient protective layer. Other weights and distributions of rubber have been used, *e.g.*, in earlier three-ply fabrics two 85gm. inter-ply layers were used. In many fabrics an inner facing† has been used of 15, 30, 40 or more gms./m².

The composition of the rubber proofing varies somewhat with different makers. Normally it is about 95 per cent. hard fine Para rubber, from 1 per cent. to 3 per cent. of sulphur, often together with say 3 per cent. or 4 per cent. of inorganic substances such as lime, magnesia or litharge as accelerators of vulcanisation. Some proofers use no mineral accelerator. For standard British fabrics not vulcanisation is specified. Experience in this country with cold vulcanisation has not been successful. There has been no attempt to set up a standard degree of vulcanisation for the two excellent reasons that no one knows which is the best one, and if they did, they would not in general be able to test a finished proofing and say whether it had or had not been brought to that optimum degree. It may be said here that the percentage of combined sulphur, a figure correlated with degree of vulcanisation for the same type of mixing, varies in British proofings from about 0.3 to nearly 2.0, though more usually between 0.5 and 1.5. No connection between this and permeability can be traced.

In testing proofed fabric, the permeability to hydrogen is measured with the fabric at normal humidity and 20°C. The figures for two and three-ply fabrics as described earlier may not exceed 12 and 10 litres/m²/day respectively. Two-ply fabrics, at any rate, are usually a litre or so below the specified figure. The connection between weight of proofing and permeability is not very clear. With rubber films there is a regular decrease in permeability as the specific weight increases. Such rubber film has, however, weight for weight, a very much higher permeability than rubber proofing of the kind just described placed between plies of cotton. The evidence on weight and permeability with regard to proofed fabrics, as distinct from films of rubber, is by no means unequivocal. In one instance the figures for a number of two and three-ply fabrics by the same maker were compared. The former had almost exactly half the weight of proofing of the latter, yet the mean permeability of the two-ply was very close to that of the three-ply. On the other hand, there are numerous examples of pairs of fabrics, each having the same between plies layer, and one having, in addition, a facing of rubber where the faced fabric has a decidedly lower permeability. Two-ply fabrics of the type already described with an outer protective layer frequently show on weathering a small immediate rise in permeability, and then if the protective coat is a good one, no further rise for a long time. This change corresponds to the early breakdown of the protective layer as a gas retainer which function is clearly performed to some extent when quite new. There are data

† *i.e.*, next to the gas and therefore sometimes called the "gas layer," a term open to objection. In the schemes for two and three-ply fabrics given earlier this layer would head the list.

of these kinds in abundance, but they do not settle the point. They all deal with comparison between one and two and three layers of proofing. There is unfortunately no set of permeability data for a series of fabrics having different weights of inter-ply rubber of the same kind and applied in the same way. This matter of permeability and weight has an obvious practical bearing, and it is of some theoretical importance in connection with the mechanism of the passage of gases through rubber membranes.† In practice, for framing specifications, the rough view is taken that the more proofing there is the better the fabric should hold gas. This is demanded and obtained. The fact that this has no bearing either way or any theory since the specification requirements may leave the proofer, or at any rate the ideal proofing with, so to speak, plenty to spare, leads to a further observation.

The material used for the (statistical) investigations, by which it was sought to discover what relationship, if any, existed between weight of proofing and permeability, may have been very unsuitable. The method of spreading is very important for the attainment of low permeability. It is necessary to spread a 100gm. layer in a number of thin successive coats. The proofers who made the fabrics from which the statistics were obtained were working to specification, and had merely to keep the permeabilities of the different types below or not exceeding certain values. The fact, therefore, that with 200gms./m² and with 100gms./m² of proofing they produced fabrics with nearly identical permeability proves—well, it proves that they did it, and not very much more unless it is quite certain that in each case with the large majority of pieces proofed the very best possible spreading was being done.

It may be stated here that it is possible too much stress has been laid on low permeability to the neglect of other qualities, particularly endurance. Standards, of course, have to be set up, and they imply measurement. Permeability is readily measured, but up to now no endurance test that can be usefully incorporated in a specification has been devised. "An English Summer," which was once suggested as a trial period, is scarcely a standard quantity. (The question of endurance is discussed more fully in the sequel.)

Permeability is largely affected by temperature, to some extent by humidity, and probably by tension. The first, the temperature effect, has been studied fairly well in a preliminary manner. The temperature coefficient of permeability is positive and large, viz., about 4 per cent. to 5 per cent. per 1°C. Higher humidity lowers permeability, but the effect for humidities short of saturation is small for normal fabrics. The effect of tension does not seem to have been examined. To test the permeability of fabric in tension would not be easy with any of the existing forms of apparatus unless the tension were produced by high excess gas pressure on one side and that would introduce undesirable complications. Small pressure excess has little effect on permeability. It was usual to test with a hydrogen excess pressure of 30mms. of water, but it makes no practical difference if the gas is at atmospheric pressure, at least with normal fabrics.

The permeability test to hydrogen is the one that is always made. Yet permeability to air is in many ways the more important property of the fabric. The loss of hydrogen through permeability is usually small and not costly to replace. But the entrance of air lowers the purity of all the gas in the envelope, reducing lift and tending towards the formation of an explosive mixture. The passage of nitrogen and oxygen through rubber proofing does not take place at rates in accordance with Graham's Law. Diffusion proper may be operative, but it is masked by some other effect, probably differences in the absorption of the two gases by rubber. Measurements on air, nitrogen, and oxygen permeability have been made for a number of airship fabrics. Taking the hydrogen permeability

† It is not possible to discuss this here. Anything adequate would be lengthy.

as unity values for oxygen at 15.5°C. ranging from .25 to .32 were found, and on one fabric for nitrogen the value .14.

These values may, of course, not be correct at other temperatures.[1] It follows from these figures that, from air, nitrogen enters the envelope about twice as fast as oxygen (assuming permeability proportional to partial pressure). In (qualitative) agreement with this, it is found that the non-hydrogen fraction of the gas in the envelope is richer in oxygen than ordinary air is. When the amount of impurity is small the proportion of oxygen is greatest,[2] and as the total impurity increases it approaches more and more to air in composition as regards oxygen and nitrogen. There are two (or perhaps three) reasons for this. The rate of entry of oxygen will fall off faster than that of nitrogen because the difference in partial pressure of oxygen on the two sides of the fabric will diminish more quickly than the corresponding value for nitrogen. Secondly, to make good actual loss of gas the envelope will be repeatedly replenished with fresh hydrogen which usually contains 0.5 per cent. of nitrogen and no oxygen. Possibly there will be a small amount of leakage of unchanged air inwards, *e.g.*, from a hole in a ballonet. The subject of air permeability needs further study both for fabric and for seams in fabric.

Seams themselves are frequently responsible for a considerable fraction of the total loss of gas from the envelope, the loss taking place through the stitch holes. Unstitched seams, simply overlapped and taped on both faces have, if properly made, a lower permeability over their area than over the same area of the plain fabric. Stitching adds nothing to the strength of the seam. It cannot do so since a properly made stuck seam is stronger than the fabric which it unites. Yet for a number of reasons that need not be discussed its use is persisted in and the resultant bad effects on permeability have to be overcome as much as possible. The passage of hydrogen laterally along the textile components of the proofed fabric is the principal cause of seam leakage. How this may operate is seen most easily by constructing diagrams of simple overlap, overlapped and taped, overlapped, stitched and taped seams. The first is leaky; the second is theoretically[1] gas-tight, not because the tape is gas-tight, but because the rubber solution used seals the cut edges of the textile. The third is leaky, on paper and in practice. An earlier reference was made to fabrics having an inner facing of rubber of 15 to 50 or more gms./m^2. Various functions have been attributed to this layer from time to time and they need not all be discussed here. One of them is of importance in connection with seams, really only with stitched seams. If two lengths of stitched and taped seam be made, one in two-ply fabric having no inner face of rubber and the other in rubber-faced fabric, the seams in the latter will, other things being equal, be found to be very much more gas-tight than those of the former. The inner facing prevents the lateral passage of hydrogen along the cotton into the shaft formed by the stitch hole. There is no doubt at all about this effect. It is, however, not certain that the whole inner facing is functioning. In one test, some seams were made with fabric as described and tested. From some of the pieces the rubber facing was removed[2] up to the edges of the seam, but the seam permeability of these pieces was no higher than that of the others. It is quite possible, too, that the good effect of the extra facing can be produced by thorough impregnation of the first coat or two of inter-ply rubber. This experiment is being undertaken.

Seam permeability is stated in litres/lineal metre/day. From tests on pieces

[1] It is stated that at 40deg. C. the air permeability is equal to the hydrogen.

[2] In the " air " impurity as much as 40% (instead of 21%) has been observed to be oxygen. On the figures given for oxygen and nitrogen permeability so high a figure should not be possible, but the discrepancy is not large.

[1] And practically too in the sense explained earlier in this paragraph.

[2] This may be done by rubbing gently with a piece of raw indiarubber

having seams across them the permeability in these terms can be calculated if the fabric is sufficiently uniform for an estimate to be made of the permeability in the non-seam region. With rubber-proofed fabrics an approximation is possible, but the better the seam the greater the uncertainty as to how much is real seam permeability. The seam, of course, occupies a certain area, say 400 sq. cms. per metre of seam. From this it can be seen that with normal fabrics of 10 to 12 $1s/m^2$/day permeability there is no real excess of permeability due to the join when the seam permeability is of the order of 0.5 1/metre/day. In non-rigid envelopes the total length of seams in fabric separating gas from air is very roughly 2 metres for every square metre of fabric. Seam leakage need therefore only be about 5 1s/m/day in order to double the all-over permeability of the envelope. This figure is frequently exceeded and may indeed rise four or five-fold with unfaced fabric even when new. Good workmanship can however do much to keep down seam leakage even with fabrics theoretically bad for seaming, and it means in this case plenty of rubber solution well rubbed in.

The above summary relates principally to new seams. There is not much systematic information about different types of used seams. Another aspect of seam leakage that needs attention is that of their air permeability under various pressure conditions and its relation to loss of purity of gas in the envelope.

Endurance and Deterioration.

Good rubber-proofed fabrics that are stored at a normal temperature and shielded from light retain their properties unaltered for a long time to be measured in years. In service they deteriorate more or less rapidly, the cotton losing strength and extensibility and the rubber becoming more porous, usually consequent upon discernible chemical change. The agents causing deterioration are light, heat, and tension. Of these the principal one, either directly or indirectly, is light. In the development of airship fabrics it is noteworthy how one point at a time has received almost exclusive attention. In the early days it was insufficient scouring, acidity in the cloth and means of overcoming it.[1] Then the importance of protection from light was to the fore, the nature of the aluminium facing was considered, and the necessity for a pigmented layer under the aluminium (still imperfectly practised) insisted on. There is still more to be done on this subject, but it is, in the writer's opinion, time that tension effects had their turn. This view is based on experiments made during last summer which will be referred to briefly later in this section.

The action of light on cellulose has been studied by Aston, who used linen thread. No doubt the results apply also to cotton. He found that visible light has scarcely any effect and that the specially active rays are in two groups in the ultra violet. He further found that the rapidity of attack was greatly reduced by the removal of oxygen. In agreement with this it has been shown that the product of the action of ultra violet light on cotton in air has the properties of the oxycelluloses. The textile cannot, of course, be protected from oxygen, but it can be more or less completely shielded from light. The rubber is oxidised in light and air, and apparently even more readily so is the free sulphur always in the proofing. The sulphuric acid arising from this is a further cause of deterioration of the cotton. It may be observed that some of the free sulphur nominally in the proofing is, in a new fabric, actually in the cotton textile, and on oxidation is favourably situated for attacking the cotton. It is noteworthy, too, that light stopping protective facings, judged to be good by the fact that the inter-ply rubber deteriorates very slowly, do not prevent the relatively rapid oxidation of the free

[1] It should have been mentioned earlier in describing the standard cottons that they are specially scoured and afterwards treated with a dilute weakly alkaline substance, sodium acetate, to counteract acidity. These processes were worked out about 1915 at the Manchester School of Technology.

sulphur in the top textile and inter-ply rubber. The rate of oxidation of the rubber may be judged by the acetone extract it yields. In a well-protected inter-ply rubber whose acetone extract on six months' exposure (January to June) only increased from 5.1 per cent. to about 7 per cent., the sulphur decreased from 1 per cent. to 0.25 per cent. Heat accelerates the decay of rubber in the light, and also the attack on the cotton of the acid from free sulphur. The action of heat alone on rubber in the absence of light is not comparable with the action of light. No judgment of the probable weathering quality of a proofing can be based on heat treatment tests. Experiments on the artificial weathering of proofed fabrics using the mercury vapour lamp have not proved a satisfactory substitute for exposure out of doors. Cotton is relatively more and rubber much less attacked by the ultra violet lamp than in the natural weathering test.

Methods of protection.—All these aim at keeping light away from the rubber, cotton or both. They include :—

(i.) Reflecting facings of aluminium.
(ii.) Pigmented rubber facings.
(iii.) Dyes in the rubber.
(iv.) Dyes in the cotton.

Fabrics could be selected to typify each of these four methods used separately as well as (i.) with (ii.) and (i.) with (iii.).

It is important to reflect as much light[1] as possible, and in British airship practice the aluminium facing has been relied on for this, no systematic use of, *e.g.*, white pigments in addition have been made.[2] No aluminium facing alone has ever been successful in giving good protection. The best facings are made by printing aluminium powder on the rubber protective layer. Aluminium facings are nearly always patently discontinuous even when new. In some cases large amounts of the powder have been incorporated in the outer rubber layer, but this weathers badly and soon falls off. A printed aluminium facing used in conjunction with a suitably pigmented rubber layer immediately beneath has been found the best of all methods yet tried in service if the protection of the fabric as a whole be taken as criterion. The only pigmentation that has been much used and found successful is customarily referred to as the "heavy litharge" layer. It is simply the use of a high percentage, up to 20 per cent., of litharge in the outer rubber layer. Its virtues have been attributed to opaque colloidal lead sulphide formed by reaction between litharge and sulphur during vulcanisation. Lead sulphide is undoubtedly present, but only some 10 per cent. of the lead appears to be in this form.

Method (iii.), the use of suitable dyes[1] in the rubber, has been found very successful in protecting it from oxidation. The dyes have a marked absorption in the ultra violet. Rubber so treated may be exposed for months, at any rate, in this climate, and show scarcely any increase in either acetone extract or in permeability. A comprehensive series of weathering tests in Egypt on fabrics protected in this way is now in progress in conjunction with the manufacturers. As hitherto used, these dyes have failed to protect the cotton. In fact, no dye protection for cotton has been successful.[2] Generally, dyed outer cottons with no outer rubber have been for ground camouflage. Such dyed cottons afford slight transient protection to the rubber.

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[1] Total incident radiant energy would perhaps be a better term.

[2] One is being tried in an exposure test at present.

[1] The method has been patented by the North British Rubber Co. An example is the use of Toluene — azo — toluene — azo — B Naphthol.

[2] An alizarin dye used in an experimental fabric weathered in Somaliland was favourably reported on, but no use appears to have been made of it in practice. (Barr A.C.A., Report R and M313.)

The part played by tension is causing deterioration on exposure is very important. Until recently most weathering tests have consisted in the exposure of pieces of fabric held in a frame but not under any tension. From comparative weathering tests on pieces of fabric with and without tension it is found that the rubber in the tensioned pieces has perished more than in the untensioned. In certain fabrics a partial explanation at least is very simple. As a result of stretching under tension the outer rubber film becomes roughened and the aluminium no longer lies as a smooth layer but is easily rubbed away. Briefly, tension has made the whole fabric more accessible to light. It seems probable, however, from some other results that tension acts in other ways too. Three different fabrics were made the subjects of comparative weathering tests of this kind. Two of them had what proved to be relatively poor outer facings which roughened and fell away to some extent as described above. The other outer facing was excellent, being a "heavy litharge" rubber layer topped with a good aluminium coat of considerable permanence. With the first two there was greater loss of strength of the top ply of cotton than in that ply of the comparison untensioned pieces. With the third fabric the loss of strength was negligible both in the loaded and unloaded pieces. These strength data may be taken as some indication of the relative light penetrations, *i.e.*, considerable in the first two, little in the case of the third. Yet all these showed marked change in the inter-ply rubber. The first two signified this change by increased acetone extract and drop in permeability. The third showed a large rise in permeability and only a small change in acetone extract.

The General Course of Deterioration.

The conclusions drawn with regard to this will not in general be the same when based on exposure tests with untensioned pieces as when based on the examination of samples from actual service. Exposure tests may sometimes point to the rubber outlasting the textile. Experience with fabrics in service on the whole points to the opposite conclusion. An exception must probably be made in the case of the dye-protected rubbers. It is obviously better, since the fabric cannot be everlasting, for it to become useless through loss of gas-tightness than through loss of strength. Oxidative decay of the rubber (the inter-ply rubber here is intended) may follow one of two courses in nature of products and consequent effect on permeability. In the earlier stages there may be either a steady and decided fall in permeability, sometimes to 2 or 3 litres/m^2/day only, or a very gradual, scarcely perceptible rise.[1] Which of these two happens depends immediately on whether a soft and tacky or a more or less dry and harsh oxidation product is formed at the start. Following the fall of permeability will be a sudden and large rise as the soft product hardens or crumbles.

It is not quite clear what determines the course that will be followed. Broadly it appears to depend on rapidity or slowness of oxidative attack. If it is rapid, the soft product and lowered permeability will be encountered. If it is slow, the other product and condition. It is quite certain that in some cases, at any rate, the same proofing can follow either course according to the nature of the exposure.

The actual seriousness of a given loss of strength of the outer[1] cotton will depend mainly on whether it is the bias or straight ply. On this question of bias or straight for outer ply there have been many alternations and different practice has obtained in different branches of the service at the same time. The many reasons, good or bad, for these changes cannot be discussed here. It is now agreed to put the bias ply outside. In this case a considerable weakening of that ply means little loss in tensile strength of the whole fabric. And further, the

[1] This may be preceded by an increase on the original value within a few days of first exposure due to rapid loss of any gas-holding properties by the outer protective coat, if present.

[1] It is clear, of course, that the attack is from without.

bias ply still contributes its anti-tearing qualities not seriously impaired when it has lost considerably in strength individually. This is on condition that the rubber layer between the plies is still substantially sound. If the rubber has decayed in such a manner as to become soft and infiltrate the yarns of the textiles, glueing them into what is, in effect, a sheet of continuous material, the fabric will have a dangerously low tearing strength though it may have a good tensile strength when unwounded. For the bias ply to do its work there must be adhesion to the straight ply, but not adhesion that has become amalgamation.

Finally, on the subject of endurance, there are several cases known of large increases of permeability with no sensible chemical change in the inter-ply rubber layers. Up to now it has received no explanation.[1] It does not seem at all certain that tension on the fabric is a necessary prerequisite condition, for one or two cases of it are known to have occurred in ordinary non-tension weathering tests. It does seem probable that it is confined to one type of proofing. The increases in permeability are from, say, 10 or 12 $1s/m^2$/day to 40 or 50 or even more. The subject is still under investigation.

Classes II. and III., *i.e.*, Fabrics for Rigid Airships.

From the foregoing short account of the fabrics of Class I. it will be seen that though there are serious gaps, a good deal of systematic work has been done and a more or less coherent body of knowledge put together. This is not true to the same extent of the fabrics in Classes II. and III., though these are and will be ahead of the others in importance. The properties and problems of these fabrics are in general quite different from those of the fabrics in Class I. One consideration of great importance for the latter does not arise in the same way with fabrics for rigids, and that is the tensile strength. The strength of the fabric of a non-rigid envelope is a principal measure of the strength of the ship in a way that is not true of either kind of fabric in a rigid airship. The strengths required for the latter fabrics are uncertain. Possibly the greatest stresses they ever experience are those imposed when the gas bags and outer covers are being put in their places in the ship.

II. *Gas-bag fabrics.*—The two requirements are low permeability and small specific weight. The strength required is not great. Other necessities as flexibility and (as far as possible) water repelling non-hygroscopic character are to give permanence to the principal qualities.

In almost all cases gas-bags for rigid airships consist of goldbeaters skin stuck to cotton fabrics. Silk and a mixture of silk and cotton have also been used. No substitute for goldbeaters skin has yet been satisfactorily applied on a large scale, though experiments on this point have been made and are being continued with other animal membranes than the true goldbeaters skin as well as with artificial films. The real goldbeaters skin is the membranous covering of the caecum of the ox. In size it varies from about 27in. by 6in. to 40in. by 10in., and in weight from 14 to 28 $gms./m^2$ under ordinary humidity conditions. The weight of skins when on the fabric will be rather greater because of overlaps, say 25$gms./m^2$ for an average single layer. For storage and transit the skins are packed in barrels of salt crystals. Before use they are thoroughly washed, scraped free from most of the adherent lumps of fat, and then soaked in a 5 per cent. aqueous solution of glycerine which appears to be preferentially absorbed from the solution by the skin to a noticeable extent. The glycerine is to maintain flexibility. The cotton to which the skins are attached is D quality, *i.e.*, 65$gms./m^2$, and it is proofed with vulcanised rubber 20$gms./m^2$. The proofing is to form a basis on which rubber solution can be spread. This is done thinly with a pad, not a brush, and several coats are used. The skins, wet with glycerine

[1] See a discussion of the matter in T.1159 and R and M.584, both reports of the former A.C.A.

solutions, are applied to this[1] and good adhesion is obtained. There is an overlap where each skin joins its neighbour. If two layers are applied, the second layer is applied to the first with no adhesive between and so that the longitudinal directions of the units of this layer are rectangular to that direction in the other layer. The strength of goldbeaters skin in the transverse direction (*i.e.*, the hoop direction in the animal's intestine) is about twice that in the longitudinal direction. When the skins are laid and the fabric is "air dry," it is sometimes varnished, in present practice an oil varnish being used. That is a brief description of present British practice. A fabric is produced having a weight usually below 160gms./m² when double skinned and varnished. This refers to normal humidity. The variation in weight with humidity is not large unless excessive glycerine has been used. The permeability of skin-lined fabric is not very uniform. Double-skinned fabric of the type described is frequently below 0.5 1/m²/day. It is quite commonly lower; it is probable that most of the permeability observed in normal pieces is not through the skins but through minute faults. In German practice the adhesive used is a special glue and, at any rate recently, both skin and cotton faces after make-up are treated with a water-repellent coating. The German method and product both differ in several important particulars from the British. Experiments with new adhesives and new methods of manipulation are now in progress here.[1] Differences in behaviour and properties between the two types of fabric will now be briefly discussed in connection with the endurance and causes of deterioration of skin-lined gas-bag fabrics.

Gas-bags are protected by the outer cover from the weather and from light, and no question therefore arises of the deterioration of the textile or rubber (if used) through the action of what is, with other fabrics, the most potent harmful agency. The life of the gas-bag is the life of the skin lining, and methods of protection have for their object the maintenance of the goldbeaters skin. This is mainly a mechanical and not a chemical question. Considering first the use of rubber adhesive, the skins are stuck by its means to cotton fabric. This is very extensible even at low stresses. The skin also is extensible if it is kept in a moist condition. To do so is the function of the glycerine, which is not a softener *per se*, but which being hygroscopic, keeps in the skin an amount of moisture greater than it would otherwise have. If a piece of new skin-lined fabric of this type be broken in a testing machine, it is found that the skin remains intact up to the point of rupture of the cotton even though extensions of, say, 10 per cent. and 17 per cent. in the warp and weft directions are obtained. If, however, such a fabric be pulled on the bias and distorted with accompanying much greater extension than in the direct pull, the skin will be cracked. Or, if the skin be dry, as after exposure in warm air or low relative humidity, a small extension accompanying direct pull may be enough to break the skin. If the warmth and drying be carried still further the contraction of the skin cannot be followed by the cotton, with the result that at a region of weaker adhesion they part company and a pucker is formed. If this is smoothed out by tension in this dry condition, once more the skin will crack. If a piece of fabric which has been brought to this puckered condition by heating in a dry oven at about 70°C. be left for a time in air at ordinary humidity, it will recover its extensibility and the puckers can be pulled out without cracking the skin over them, though the separation of skin from fabric in that region of course persists.

A similar puckering and relaxation is obtained when such fabric is exposed in a climate with large variations in temperature and therefore in relative humidity. The latter and not absolute humidity is the moisture control. It appears that

[1] Numerous important practical details and workshop methods for systematic and rapid working are omitted.

[1] It is unfortunate that this paper is being written at a time when interesting developments are in their early stages and by no means ripe for description or discussion.

after a number of alternations the skin loses its power of recovery even in a moist atmosphere, and is in some way fundamentally altered.[1]

The results suggest the trial of softeners that do not depend on moisture for their action. This trial is being made.

The behaviour of glue-stuck skin-lined fabric is very different. There is no puckering on dry heat treatment with these, and they can, even when dry, be stressed considerably more than fabrics of the other type without any resultant rupture of the skin. The glue alters the extensibility of the textile and under moderate loads, at any rate, takes control. Further, the glued textile will tend to expand in a moist atmosphere and contract in a dry one, behaving in this way like the skin or, at any rate, accommodating the one component to the other. The whole question of the use of glue as adhesive including composition of glue, mode of application, pre-treatment of textile and skins, as well as after treatment of the fabric with varnishes and water-repellents, is now engaging attention, and it would not be profitable to add more on the subject now.

It may be observed that neither glue-stuck nor rubber-stuck skin-lined fabric will stand crumpling when warm and dry without serious permanent increase in permeability.

The permeability of both types of skin-lined fabric is usually, but not always, lowered by increase of humidity. This lowering with the German glue-stuck fabric is often very large. It is to be expected that this effect would be greater when glue is the adhesive. The Germans appear not to aim at as low permeability as is expected with British fabric. This is in accordance with their lavish provision of hydrogen. It is difficult to arrive at any reliable result for the all-over permeability of either type of bag. The only experimental method is to make loss of purity curves. There are numerous sources of error to consider, and even leaving these out of account the data do not lead to a hydrogen permeability result without an assumption as to the relative air and hydrogen permeabilities. It is true that loss of purity itself is the important result, but if the calculations from this to hydrogen permeability cannot be made, neither can the reverse one from laboratory determinations. Qualitative comparative results must suffice unless a fairly comprehensive investigation be undertaken of the relative air and hydrogen permeabilities of a number of skin-lined fabrics.

The skin, as already stated, has appreciable strength and contributes to the tensile strength of the complete fabric. Skins stuck with rubber also greatly increase the resistance to tearing, but glue-stuck skins do not, probably because of the impregnation of the textile by the glue. The following are typical figures for the two kinds of skin-lined fabric.

Kind of Fabric.	Tensile strength Kilos/metre warp direction.		Tearing strength for "in. cut as percentage of unwonnded.	
	Complete fabric.	Cotton ouly. Skin removed.	Complete fabric.	Cotton (nly.
Rubber stuck (British) ...	825	670	65	40
Glue stuck (German) ...	860	608	40	40

Class III.—Outer Covers.

Ideally the outer cover would consist of a series of plane surfaces covering

[1] It is possible that this is a result of other changes and not directly of the humidity alternation, *e.g.*, of the development of acidity. There is no evidence on this point yet, but it is hoped to obtain some from tests now in progress.

the rigid framework and, with this framework, defining the shape of the ship. This leads at once to the requirement that the outer cover shall be and remain taut. Further, it must be weatherproof so as neither to admit rain to the inside nor get waterlogged itself. It should also, as an extension of its waterproofness, be water-repellent. It must, for retention of its own strength and for protection of the gas-bags, be opaque to harmfully active light; and, principally to avoid superheating of the gas, must reflect as much incident radiation as possible. Added to this, it must have the lowest possible specific weight.

Linen, mercerised cotton and plain cotton have been used as the textile components. The two latter are in use at present. Various doping schemes used in the past have been only moderately successful and it would serve no useful purpose to give an account of them here. Some single-ply cotton and linen fabrics proofed with rubber having an aluminium finish were tried experimentally and subjected to weathering and other tests before the importance of tautness in the outer cover was fully realised. The dopes at first used were similar to aeroplane dopes but of less contracting power. Now that the strength of the framework is known to be sufficient, more powerfully contracting dopes, in all essentials the same as aeroplane dopes, are used. These consist essentially of cellulose nitrate or acetate, the latter having been used almost exclusively in the past, but the former is introduced in the latest doping schemes for reasons to be mentioned later. The function of the dope is first and foremost to produce tautness.[1] It is applied in a suitable solvent to a fabric already in slight tension. When the dope is dry, considerable tautening is found to have taken place, the actual final tautness being dependent on the nature and amount of the dope and the initial tension of the fabric. Light absorbing pigments are introduced for the protection of the textile. A red one, which has been found the best, consists of an oxide of iron. The top coat contains aluminium powder to provide a reflecting surface. This is only the briefest outline description of a doping scheme as now applied. A few of the more important details, additions and alternatives to such a scheme will now be briefly discussed.

The maintenance of tautness is a much more difficult matter than the attainment of a good degree of initial tautness. In a moist atmosphere the tautness is soon reduced through the absorption of moisture by the dope. It is stated that by using very little dope an ever-taut fabric can be obtained because a balance is struck between slackening of the dope and contraction of the textile, but under such conditions probably a sufficient degree of waterproofness, protection for textile and general robustness would not be attained. Experiment has shown that pigmentation of the dope (initially done for quite another reason) is one of the best means of minimising the slackening effect of exposure in moist air,[1] and the best results are obtained with pigment in every coat of dope applied. Pigmentation of the right kind is thus excellent. It saves cellulose acetate, protects the textile and maintains tautness under unfavourable conditions. The use of cellulose nitrate dope instead of acetate has to be considered in this connection, too, for it is less affected as to tautness by changes in humidity. It is actually being employed now for some parts of outer covers, and is not used throughout only because of its greater inflammability. The question of outer cover tautness, so important on account of its bearing on speed, among other things, is a rather

[1] Some apology is needed for the introduction of these elementary facts at this date in a paper to an aeronautical society. It is done for the sake of a (limited) completeness and as introductory to the further description. The great improvements in aeroplane dopes by which airship outer covers are now benefiting are largely due to the chemical staff at the R.A.E., and much of this section is taken from their reports where these matters are discussed in detail and with the support of a wealth of experimental data.

[1] It should be mentioned that earlier observations gave rise to the precisely opposite statement, but the more recent experiments referred to above are very complete and probably their authors had the earlier observations before them, and were satisfied that they were not generally true, though no mention is made of this.

bigger problem than that of the tautness of aeroplane wing covers. The areas involved are so much greater, and the view is held that dope cannot be expected to do all that is wanted in this way,[1] and in fact, the recent practice is to give assistance by attaching the cover by inside ties to diagonal wires.

Additional weatherproofness is sometimes attained by a finishing coat of varnish (containing aluminium powder). Varnish here means a flexible nitro dope containing, *e.g.*, castor oil.

In one acetate dope, linseed oil[2] is included as a water repellent, for which purpose it appears to be fairly efficient.

For the prevention of superheating there is the reflecting aluminium finish. The efficiency of this varies considerably and depends largely on the nature of the aluminium powder used. It seems possible that the reflecting power of aluminium powder might be assisted by the use of zinc white which, out of a large number of opaque substances tested, was found to possess the necessary radiation characteristics in the highest degree, *i.e.*, low absorptive power in the region of maximum sunlight intensity and high emissive power with small rise of temperature. It is probably not so effective in protecting the textile as the iron oxide pigment, but that might reinforce the zinc white in a layer beneath it.

Other problems that arise with outer covers touch the methods of applying the dope. In present practice pre-doping is used, *i.e.*, a part of the dope is mechanically spread before the cover is made up. It is then laced in place and the remaining dope (and varnish, if any) is applied *in situ*. It seems likely that this will be abandoned as not making the most of the weight of dope it is desirable to add. A light pre-doping may, however, be desirable to give a slight stiffness to the fabric to prevent distortion when putting in place prior to the doping proper.

Some of the foregoing, it will be seen, deals with proposals for methods yet to be tried, and with regard to the new practice already in operation it is too early yet to speak of its performance. It is known from many tests in connection with aeroplane fabrics to give extraordinarily good protection to the textile. For outer covers, as for gas-bag fabrics, this paper comes at a time when distinctly new methods are being tried.

In conclusion, a word or two may be added on the general methods of chemical and physical approach to the problems presented by these materials. It is probably true to say that applications of rigorous scientific methods and of well understood principles are increasing, not merely in devising methods of tests but also in working out new processes and employing new materials. Examples of this are to be found in the studies of various solvents and solvent mixtures for dopes, in preliminary researches on cellulose acetates and allied bodies, and in Aston's work on the action of ultra violet light on cellulose, to name only a few examples. On the other hand, there is a wide field where empirical methods are the only ones available, and where the only good test is in an attempt to reproduce conditions of service which the material will have to endure. All weathering tests form the main example of this kind of work. It is often, moreover, an empiricism where it is not possible to select for variation and study a single factor, keeping all others constant. In the interpretation of results, therefore, judgment and a weighing of pros and cons may take the place of logical deduction. This perhaps is no drawback, for these qualities will certainly be required in devising any new material as a result of the tests, for such material must always be a compromise.

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[1] It has been suggested that a slight positive pressure inside the cover should be maintained.

[2] It is orthodox to object to the use of linseed or other drying oil in contact with textiles on the score of tendering. It is possible that in conjunction with good light-absorbing pigments the use of such oil might be free from objection.

DISCUSSION.

Mr. C. I. R. CAMPBELL said the paper was a comprehensive one and was written by a gentleman who was, perhaps, the greatest authority on the subject. A point which he (Mr. Campbell) thought required further consideration was the value to be given to the bias ply in three-ply fabrics. In non-rigid design the data available was very small indeed. In the non-rigid envelope the greatest possible strength was required, particularly in a circumferential direction. A bias ply was put in mainly for protection against accidental tearing, and no more was really asked of it than that. One wanted to get the thinnest bias ply that would do the work, and it was not known at present what was the minimum one could go to in that direction. He hoped Mr. Dyer would have particulars of experiments on that matter before very long. The figures he gave for sustained loads were very interesting and he (Mr. Campbell) had not seen them before. The fact appeared to be that a fabric could only sustain a tension of half its ordinarily expected breaking load, and this had a marked bearing on what were customarily believed to be factors of safety. It appeared that many of the factors of safety which were talked about for non-rigid envelope fabrics should be halved, as the loads were of a sustained character in most cases. Discussing outer covers, which was one of the subjects upon which research, or rather perhaps practice, was most incomplete. Mr. Dyer spoke of the importance of fireproofing. That was a point on which they all felt more strongly every day, and the evidence, he thought, showed that if acetate dope were used with plenty of pigment in it, appreciable fireproofness was secured. One did not get an incombustible outer cover, but one that would not burn freely if a light were applied to it. At the present time, when they were told airships were on the point of becoming extinct, it was particularly valuable to have this information collected and put forward in this authoritative manner, and they owed Mr. Dyer a debt of gratitude for having taken the work in hand.

Dr. GUY BARR said with regard to the strength of two and three-ply fabrics, the lecturer mentioned that the important things to consider were the relations between the strength of the individual fabrics and that of the complete cover, the strength of the wounded fabrics, and the effect of sustained loads. He (Dr. Barr) would suggest a further important point—extensibility under compound stress, which was important not only from the point of view of the adjustment of local inequalities when stressed, but also from the point of view of the actual volume of the ship. He referred to Table 7, bearing on the subject of strength under sustained loads. It would be seen that the largest percentage of the normal breaking load was retained in the second case dealt with (B.D., parallel warp). It looked to him as if a considerable proportion of the loss—in the first and third cases, at any rate, compared with the second—was due to the two plies coming unstuck under the conditions of the experiment, and that this would not occur to the same extent when the fabrics were in position with considerable pressure inside. The difference between 50 and 62 was not large, but it was a considerable proportion of the difference between 50 and 100. The remaining 38 per cent. was probably to be ascribed simply to the fact that the effect of rate of loading appeared to be most serious at the lowest rates. Mr. Dyer referred to Dr. Aston's experiments on the action of light on cellulose, and he (Dr. Barr) thought there was a small mis-statement there. Dr. Aston found that the light from the mercury arc produced the greatest deterioration in two particular portions of the spectrum, but the fact that he found those two particular portions was presumably to be ascribed not to the fact that those two parts of the spectrum of daylight were the most active, but that they were the only two in the ultra-violet part of the mercury arc spectrum studied in which there was any large amount of energy. Had any methods of protection been tried in which the reflecting facing of aluminium on a two-ply fabric had been combined with a dye in the cotton? For a long time people had been satisfied with a yellow dyed cotton, which protected to some

extent the rubber underneath, and the dyed cotton itself did not deteriorate extremely fast. The use of yellow dye showed a large improvement as compared with undyed fabric. These reflecting facings had been tried with pigmented rubber and with dyes in the rubber, but he had not seen any results of a combination of the reflecting pigments of aluminium with the dye in the cotton, and he thought that combination should be tried. With regard to the change in permeability, which occurred occasionally on storage, when there was no obvious reason why there should be a change; if one examined the fabric there was no evidence of oxidation nor of anything else except change of permeability occurring. In this connection there was an interesting observation made at the Bureau of Standards that in one or two cases permeability did not increase, but decreased to something like one-half of the original permeability instead of multiplying itself by 5, which was happened in the case to which Mr. Dyer referred. He did not know the explanation of it.

Colonel RICHMOND said he well understood Mr. Dyer's difficulty in compressing his subject into the space allowed for publication, and it was even more difficult for those who had not received an advance copy to grasp the subject properly from the précis into which the paper had been further compressed. It was a vast subject, and even the written paper did not refer to a lot of things of which he knew Mr. Dyer had intimate knowledge and on which they would all like to have information and to be able to discuss. Amongst these the most important was, perhaps, the mechanism of permeability. This was an extremely complicated business. Take as an illustration the gold beater's skin membrane used in rigid airship gasbags. This has a very low permeability to hydrogen, something like 1/200 of its permeability to water vapour. It had scarcely any permeability to petrol. These were facts which it was very difficult to explain. Also one might refer to the fact that most colloidal substances seemed to have a limiting permeability with weight. Some interesting work on this question had been done by Mr. Ritchie, late of the Kingsnorth laboratory, but it did not go far enough, and he thought this question of the mechanism of permeability should be tackled as soon as possible. He was sure it would have saved thousands of pounds during the war in that more efficient means would have been found of restoring a large number of envelopes which had to be scrapped. With regard to rubber fabrics in general, he would not prejudice the examination Mr. Dyer was going to make of the Egyptian samples by saying much, but there was no doubt that in Egypt all the dyes tried so far in the cloth were simply bleached in six weeks of ordinary weather, unless they were protected by aluminium or some other pigment. The dyes used in rubber undoubtedly preserved the nature of the rubber, but did not preserve the cloth, and of all the samples received, those coated with a heavy litharge coating outside seemed to have stood up best. With regard to skin-lined fabrics for airship gasbags, he would like to emphasise how necessary it was to obtain perfect adhesion between the skin and the fabric. There was an idea some time ago that the Germans thought it sufficient if the skin was lightly attached to the fabric, the skin merely acting as a gas-holding medium. They knew now that such a state of affairs would rapidly throw stresses on the skin which would tear it in all directions when the relative humidity of the air was low. He had repeated that experiment with synthetic films of various kinds. Provided the film was elastic and the adhesion was good, the tensile strength of the film was not so necessary as one might imagine. Mr. Campbell had emphasised the gloom of the clouds which were supposed at present to be obscuring the sun from airships, but he (Colonel Richmond) felt sufficiently optimistic about the future of them to say that gold beater's skins as a means of lining airships would not do. There were going to be so many airships that there would not be sufficient oxen in the world to supply the skins. In spite of the financial gentlemen who said there was not enough money in the country, the money would be found in other countries for aircraft development, and he was sure we should not be long in competing

successfully when once the public woke up to the possibilities of airships. With regard to substitutes for gold beater's skin, one ingenious thing the Germans had done was to grow the skins by means of bacteria, and also they found the glue used on their fabrics during the war so good that they were now making a fabric which consisted of the cotton and glue alone, without any skins, and he thought that promised very well. The aeroplane chemists had helped them enormously in the matter of outer covers, but the chief point to airship pilots, which would not strike the aeroplane chemists as being so important was the question of superheating, the question of getting the maximum reflection from the fabric. The ideal fabric was either completely transparent—which was impossible—or a perfect reflector. Of the three fabrics which had been examined for superheating in Egypt, viz., one with an aluminium surface, one with a zinc-white surface, and one with a red or gold-leaf surface, the best was the zinc-white, which had superheating under normal conditions of about 16deg., the aluminium had 23deg. and the red or gold 28deg. These were merely relative figures.

Wing Commander T. R. CAVE-BROWNE-CAVE said he did not know if they all realised that Mr. Dyer had really written two papers—the one he had read and the printed one. The complete paper contained an enormous amount of information on the very extensive research work which had been done on this subject. It would be as well if Mr. Dyer would add to the paper when printed in the Journal the detailed references to other people's work to which he had referred and also give a short bibliography. With those additions he believed that the paper would be for a very long time *the* classic on the question of airship fabrics.

The paper was obviously more complete in its treatment of the non-rigid fabric than where it dealt with the fabrics of the outer covers and gasbags of rigids. That was because a great deal more work had been done on the rubber-proofed fabric of the non-rigid. The conclusion generally drawn from the paper was probably that the rubber-proofed fabric presented far greater difficulties than the outer cover and gasbag fabrics of the rigids because of the deterioration of the rubber. One was frequently tempted to say "let us abandon the rubber and build up a non-rigid envelope fabric with an outer surface like that of the rigid and a skin-lined interior." That scheme failed because one had to get the necessary strength of the envelope by a compound fabric. Unless a substance such as rubber were used it was extremely difficult to build up a compound fabric which would have a reasonably good strength when wounded. Rubber was such an elastic adhesive that it allowed the diagonal ply to reinforce the straight plies to a much greater extent than was possible with anything else.

Mr. Campbell was very pessimistic about the deduction to be drawn from the sustained load tests. The only way in which the envelope stress could be increased to a dangerous value was by internal pressure, not by the rigging tensions which were limited by the lift of the ship. Excessive internal pressure was caused by a pilot's mistake and would only last at most a few minutes. It was not fair to assume that the envelope was going to be blown up to its bursting pressure for long periods. An interesting point was the question of unsewn seams. It had been established beyond all doubt that stitching in a seam was detrimental. It contributed nothing to the strength, and was a most prejudicial feature in regard to gastightness. But it did not look nice to fly about the heavens with seams that were stuck and not sewn, and for that sentimental reason non-rigid envelope seams were sewn. It was a curious state of affairs. One difficulty in tackling the question of the deterioration of rubber-proofed fabrics was the difficulty of reproducing the deterioration in an intensified form. When studying the deterioration of cellulose one could use mercury vapour lamps with fair confidence, but there was no artificial means of producing the actual deterioration of rubber in a more rapid form. He was rather disappointed that they had not had any remarks on that point from the rubber manufacturers. The

paper was, perhaps, rather pessimistic in that it drew attention to the various difficulties that were experienced, but more particularly with regard to rubber-proofed fabrics the development that had taken place was most creditable. In 1915 they started making envelopes of single-ply—a fabric designed to burst at 120 mm. pressure. They burst, however, when actually proof-tested at 25 mm. That was the state of affairs when Adam, Ritchie and Dyer took over the question. The last non-rigid deflated was the N.S.7. She was inflated in April, 1919, deflated for a purely mechanical defect three months afterwards, inflated again with the same envelope, and deflated three weeks ago because she was no longer wanted for service. To keep an envelope inflated for three years and have it still in an effective condition was a result to be proud of. Mr. Dyer was now free to get on with the question of the rigid fabrics, and he thought they were all confident that he could meet with corresponding success.

M. J. L. LAKE said that in going through an Elizabethan Grammar School last summer he found in the Hall the words "Disce aut discede"—"Learn or get out." The rubber manufacturers had done their best both a few years before the war and during the war to learn the requirements of balloon and airship work, and they had no desire to get out in spite of what had been said in the House during the last few days. They felt that there was a great future for airships.

He would like, as being perhaps the only representative of the manufacturers present at the lecture and only a humble representative of the trade, to thank Mr. Dyer for his learned paper which was full of most valuable information and would be closely studied by the rubber manufacturers.

As one who had come into contact with the Government officials, he would like to remark how very anxious they were to help the manufacturers now that they had more time than they had during the war. The manufacturers appreciate the ready help they were always willing to give them.

The CHAIRMAN invited other members to contribute remarks in writing, announced that the Author would reply to the discussion in the Journal, and proposed a vote of thanks for the paper.

SUMMARY OF POINTS RAISED IN A WRITTEN COMMUNICATION FROM MR. A. D. RITCHIE, FORMERLY CHIEF AIRSHIP CHEMIST.

1. Avorio considers the dimensional effect observed by him to be due to seams. Bursting tests on envelopes point to some, and possibly an important, weakening due to seams.

2. The bursting tests at Kingsnorth were done with a rate of loading less than 30lbs./in/min.; at least 10 minutes were taken to reach bursting pressure.

3. Considerable weight, in my opinion, is to be attached to the statistical evidence as to the relation of weight and permeability.

(i.) It is shown clearly that results with one specification are very variable, so that comparisons of specifications based on a few tests are misleading.

(ii.) As against the argument that the apparent similarity of permeability for different weights is due to different degrees of care in manufacture, I should suggest that a bad maker will always get many high permeabilities with light proofiings because they are harder to make, and it is only good and uniform workmanship that will show the similarity. At any rate, the following facts must be taken into consideration:—

(*a*) For some time permeability was not specified by the Admiralty; there was only a general clause about workmanship in the contract.

(*b*) The firm worst for permeability was best for regularity of weight (*i.e.*, careful spreading).

(*c*) The minimum permeability (4 litres) was strikingly regular for all makers and all specifications.

(*d*) Consideration of results for one specification showed no correlation between variations of weight and variations of permeability.

(*e*) Some fabrics with as little as 50 gms/m² between plies had good permeability.

Owing to the nature of the fabrics made there were no sufficient means to distinguish effects due to variations in weights of a single layer of proofing from those due to variations in number of layers or situation (*i.e.*, between plies or on face).

4. Is loss of sulphur on weathering due to volatilisation?

5. Impregnation of the cotton with rubber would largely prevent seam leakage, but the practical difficulties of impregnations are enormous.

6. Do the Germans soften their goldbeaters skin with glycerine? Do they use Lecithin as I suspected?

P. M. MATTHEW (communicated): The three questions of chief interest to proofers at the present time are:—

(1) The durability of proofing under tropical conditions.
(2) Its protective action on the cotton fabric.
(3) The efficiency of the seams in the various fabrics.

As the result of experience at home and in France during the past eight years in connection with balloon and airship fabrics, and during the past forty years in the Tropics with waterproof fabrics, I have no hesitation in coming to the conclusion that durability is largely, if not entirely, a matter of vulcanisation, the best method and "optimum degree" of which have yet to be determined.

Perfect vulvanisation, or "optimum cure" as it has been called, is generally understood to mean the production in rubber of its maximum resiliency and tensile strength. While it cannot be said that this is in inverse ratio to its durability under severe weathering conditions, I incline to the belief that something of the kind is the case. In saying so, I have in mind the result of a series of "weathering" tests made during the summers of 1917 and 1918 with various proofings made—

(1) With pure unvulcanised rubber.
(2) With rubber vulcanised to various degrees.
(3) With unvulcanised (but vulcanisable) rubber.

As regards the best system of vulcanisation, which is perhaps still an open question, I incline very strongly to dry heat for gas proofing. I notice you speak of finding a deposit of sulphur in the cotton of certain proofed fabrics. I think you will find it generally present in those which have been vulcanised by moist heat, in which the nature of the process prevents its escape.

As regards the various forms of protective coating on the outer surface of the fabrics, it would appear that so far a suitable combination of rubber and aluminium is the most effective. Here again the "optimum degree" of vulcanisation plays a highly important part in the matter of durability and incidentally, of course, in fixing the aluminium. I may mention that in the case of our samples (spec. No. 23 and 32) now being tested in Egypt, a red dye soluble in rubber is incorporated in the aluminium mixing, no dye being used in the cotton.

Your remarks on the subject of seams are extremely interesting, and all the observations which I made, both in this country and in France during the war, point to defective seams as the chief source of leakage in kite balloons.

By the omission of stitching this would be greatly reduced, as also the risk of damage to the fabric in making up. It has always appeared to me as the result of experience in cognate manufacture that with a gastight inner facing of rubber on the fabric, and tape with a similar weight of facing, it should be possible to make a perfect seam, and at the same time to reduce the width of the tape now in use.

With regard to gasbags for rigids, it is interesting to note that their life is that of the skin lining, and that this is probably lengthened by the use of rubber in place of glue as an adhesive. Is it possible that the trouble caused by the unequal shrinkage of the cotton fabric and the skins would be lessened were the uniting solution vulcanised? It would almost seem that were this possible it would reduce the tendency of the two to separate. It seems possible that if the cotton fabric were well stretched in scouring and finishing (though not so as to unduly reduce its strength) it might to some extent contract again with the shrinkage of the skins. The drying-up and loss of pliability in the skins is presumably due to decomposition or dessication of the animal matter. Could this be retarded by applying some antiseptic or preservative along with the glycerine?

I trust you will pardon my troubling you with a rather long letter dictated by interest in your work, and your very wise suggestion that the problems in hand call for empirical as well as scientific methods of treatment.

REPLY TO POINTS RAISED IN THE DISCUSSION.

I do not think there are any figures on the subject of three-ply fabrics referred to by Mr. Campbell. If it is desired to reduce the weight of the middle (bias) ply of a three-ply fabric it will be necessary to consider what degree of protection from tearing is to be provided.

I agree with Dr. Barr that extensibility is important, but so far as I know it has scarcely been studied. Different pieces of fabric by the same maker have different extensibilities for low loads such as are met with in practice. In sustained load tests partial loss of adhesion of plies may be operative, but the tests on single ply fabrics (linen in Table VII. and cotton in Table VI.) show that there is an effect independent of this ply separation. Dr. Barr's correction as to the inferences from Aston's experiments is accepted. My statement needed amplification. Dyes for protection of cotton with the aluminium facing as well have not, I think, been tried. Of the much lowered permeability as reported by Bureau of Standards I have met one case. Unfortunately I had very little of the material. The rubber was unoxidised but very soft.

Major Richmond refers to a subject of great interest and greater difficulty, viz., the mechanism of permeability. It is clear that the difference between gases in respect of this property are not explicable on any of the recognised characteristics of their molecules, but that a reaction, or perhaps better, a transaction, with the substance of the permeable film is also concerned in the total effect. With regard to prevention of superheating and the use of zinc-white or aluminium, I think a knowledge of the nature of the aluminium surface and of the aluminium powder used is very important for the comparison. Figures have been given for aluminium and zinc white reversing the order of efficiency stated by Major Richmond, and further trials may be necessary.

Wing Commander Cave-Browne-Cave refers to the desirability of a list of references to original papers. One that had been prepared is appended. It is not so complete as one would wish. A large amount of the work on non-rigid fabrics is contained only in departmental report principally from Kingsnorth and Manchester and few of these were published by the A.C.A. The same is true of work on skin-lined fabrics and outer covers. With the exception of three or

four papers therefore the bibliography largely refers to work done for aeroplane fabrics, but having either a general or particular bearing on some problem of airship fabrics.

With regard to the points raised by Mr. Ritchie :—(2) If the comparison tensile test had been done at an equivalent rate of loading the ratios T_b/T_t would have higher than those given.

(3) Possibly I gave the statistical evidence on the weight-permeability relation less than its deserts, but that is not to be regretted since it has called forth such a clear statement of the case from Mr. Ritchie. These points have to be taken seriously into account, though I still think the question not proven. Comment must be limited, but the reasons for failure to carry conviction to my mind are briefly :—

(1) There are few or no data on the weight-permeability relation for a single layer of proofing covering a reasonably wide range of weights.

(2) There are such data (not very numerous it is true) for films and sheets of rubber, and a roughly linear relation between weight and reciprocal of permeability has been stated, although various methods of preparation of film and sheet were involved. Further data of this kind should be obtained to place the matter beyond doubt.

(3) With regard to workmanship I should compare not so much one firm with another, but the same firm (*i.e.*, very likely the same workman) at work on light and then on heavy proofings. Long practice in the art probably enables the spreader to boil it down to "much rubber, less care; little rubber, more care." I do not assert that this is the case, but only that it is a possible explanation.

(4) I think sulphur may be, and probably is, lost by volatilisation on exposure, but that oxidation takes place as well and may predominate. My reasons are (i) that in a fabric exposed from January to June the rate of loss was no higher in the hot weather than in the cold; and (ii) that from a fabric kept during three months in a room always warm and for eight hours of the day at 40° C. the loss was less than from a piece of the same fabric exposed to the weather.

(5) I agree that impregnation of the cotton in the full sense of the term is impracticable. What was meant in the paper was the filling of interstices between the yarns. It was suggested by proofers that this might be an improvement. The full test has not yet been carried out, but a stitched seam made in a piece of two-ply D fabric, where the interply rubber had for some reason unknown been very thoroughly pressed into the cloth, gave a very much lower seam permeability than is usual with stitched seams in unfaced fabrics, though presumably this was not for the cause which might be expected to operate in a genuinely impregnated cotton.

(6) Yes, glycerine is used in German skin-lined fabric. No further search for lecithin has been made.

Mr. Matthew's remarks on the importance of correct vulcanisation are interesting, and I should like to read a full account of the experiments to which he refers, because it is a subject on which nothing seems to have been published where maintenance of gas tightness is the principal property under consideration.

There appears to be no doubt that an inner facing of rubber is highly beneficial in securing gas-tight seams, where stitched seams are concerned.

My remarks on rubber versus glue for skin adhesive were meant to favour the latter, and experiments on most examples of the two types support my argument. A vulcanised rubber as adhesive should certainly be tried.

The desiccation of the skins on exposure in hot climates seems to reach a

point at which pliability cannot be restored by fresh treatment with glycerine. Whether this is animal decay or attack by decomposition products of the rubber adhesive and proofing does not seem clear.

BIBLIOGRAPHY.

In an account, such as the foregoing, which is principally a description of broad results based on much detailed experiment it merely confuses to refer to individual original papers pertinent to the subject under discussion at the moment. A list of the more important papers is therefore appended, roughly classified. On some important matters there are no published reports available, the only papers being confidential official ones.

The classification of the bibliography does not follow the divisions used in the body of the report. It is sufficiently indicated by the sub-headings.

The letters T. and R. and M. are references to the well known A.C.A. reports.

Strength (new fabrics).
T. 1204.
R. and M. 23, 29, 37, 180, 182.
Strength (effect of light, acidity).
T. 1019, 1381.
R. and M. 430, 585.
Permeability.
T. 998, 1124, 1197, 1224.
R. and M. 22, 232, 317, 360, 435, 447, 513, 584.
Weathering (non-rigid fabrics).
T. 602, 602a, 900, 1157.
R. and M. 313.
Dopes. Material (including solvents).
T. 816, 1269, 1412, 1502, 1550.
Tautness.
T. 1193.
R. and M. 569, 606.
Radiation and superheating.
T. 993.
R. and M. 329.

Bureau of Standards, technologic paper No. 128.

RIGID AIRSHIPS.

Two Lectures delivered by J. L. Bartlett.

LECTURE I.

Introduction.

In this lecture it is proposed to deal with the general aerostatical principles governing the flight of lighter-than-air craft, and also to describe briefly the various types of airships, with special reference to the rigid airship.

The future of lighter-than-air craft is undoubtedly dependent upon the development of the rigid airship, in which type of ship efficiency and performance increase at a greater rate than the gross lifting capacity.

To understand the working of a large airship it is essential to have a thorough grasp of the elementary aerostatic principles governing the flight of an ordinary free balloon, so it is proposed, first, to outline these principles and then to pass on to the non-rigid, semi-rigid and rigid types of airships, all of which are virtually balloons of varying type, rendered dirigible by the fitting of means of propulsion, and navigable by the introduction of controlling surfaces.

Aerostatical Principles.

All lighter-than-air craft depend for their lifting power on the displacement of air by a gas lighter than air. All gases lighter than air will give a lifting effect in air, but the maximum effect will naturally be obtained when hydrogen, the lightest known gas, is used.

Pure hydrogen at a temperature of 60°F. and barometric pressure of 30 inches weighs 5.33lbs. per 1,000 cubic feet.

Dry air at the same temperature and pressure weighs 76.59lbs. per 1,000 cubic feet.

Therefore in a balloon inflated with pure hydrogen, the gross lift at the above temperature and pressure would be 71.26lbs. for each 1,000 cubic feet of hydrogen that the balloon contains.

Small changes of pressure and temperature have a considerable effect upon the lift of hydrogen, *e.g.*, the figure of 71.26lbs. at 60°F., 30in. pressure, is reduced to 66.58lbs. per 1,000 cubic feet when the barometer pressure is 29in. and the temperature is 70°F.

The hygrometric state of the atmosphere also affects the lift. The effect is relatively small, but is always allowed for in the accurate determination of the lift of a ship. Damp air is lighter than dry air, therefore our lift is always decreased on account of dampness. The decrease rarely exceeds .30lbs. per 1,000 cubic feet.

It becomes expedient for the purposes of design and comparison to adopt some standard of temperature and pressure, or what amounts to the same thing, to adopt a standard of lift per 1,000 cubic feet of hydrogen, and the *standard condition* taken in this country is a lift of 68lbs. per 1,000 cubic feet.

Hydrogen used in a balloon or airship is not pure, and the impurities consist mainly of air. Hydrogen for inflating purposes can be produced at about 97 or 98 per cent. purity.

In the experimental determination of the actual lift of an airship the hydrogen purity is measured and an allowance made. If the purity of the hydrogen were

97 per cent. our lift of 71.26 lbs. per 1,000 cubic feet at 60°F. and 30in. barometer would become 97 per cent. of 71.26, which equals 69.12.

As a balloon rises the gas with which it is inflated expands. This is due to the fall of pressure exerted by the external atmosphere. If the neck at the bottom of the balloon is open, gas will be continually escaping as the balloon rises, the balloon however remaining full, the gas merely becoming less dense. The temperature also falls as the altitude increases. Fig. 1 shows curves of the variations

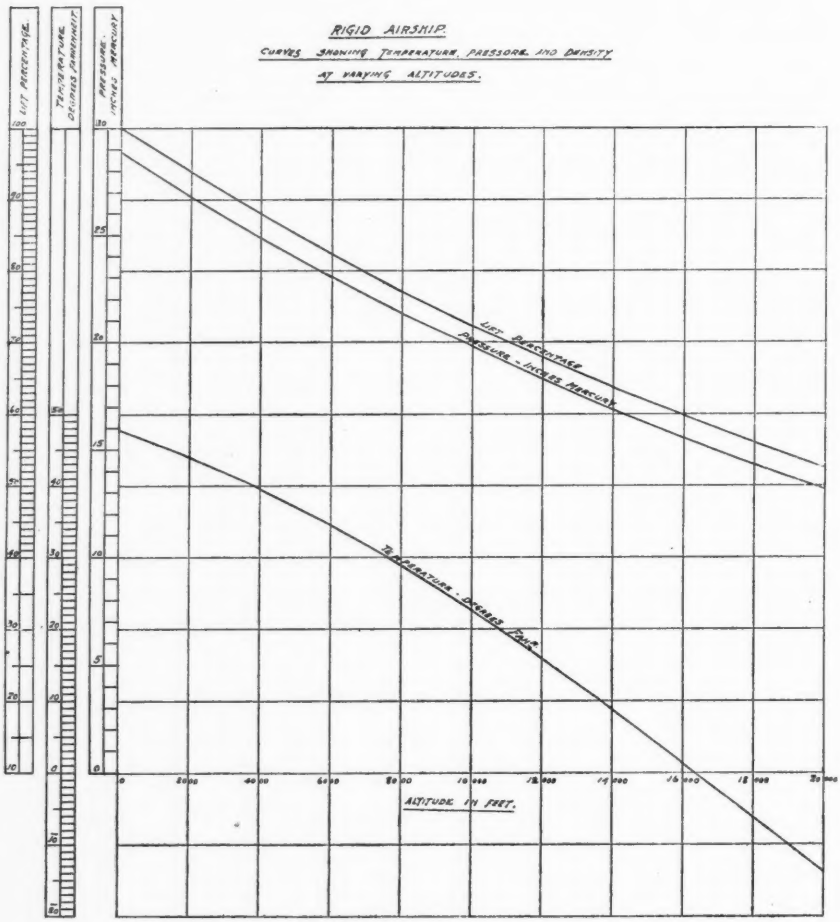


FIG. 1.

of pressure and temperature with altitude. Knowing the pressure and temperature at any particular height, the density of the air and hydrogen can be readily determined, and from these results we can plot a third curve giving the lift of 1,000 cubic feet of hydrogen at various altitudes as a percentage of its lift at ground level.

As an example, suppose we have a balloon of 20,000 cubic feet capacity inflated just full with hydrogen. Assume standard conditions of 68lbs. lift per 1,000 cubic

feet, and suppose that the balloon weighs 300lbs. and men 320lbs., that is, our total fixed weight is 620lbs.

Our gross lift is 20 × 68	=	1,360lbs.
Our fixed weight	=	620lbs.
Therefore the ballast required will be		740lbs.

As ballast is thrown out the balloon will rise. From the percentage lift curve we find that at 8,000ft. our gross lift is 77½ per cent. of what it is on the ground, therefore in order to reach 8,000 feet the amount of ballast discharged will have to be 22½ per cent. of 1,360lbs. (our gross lift), *i.e.*, 306lbs. of ballast will have been thrown out. The balloon will still be just full.

Let us trace the descent from 8,000ft. To start the descent, a little gas must be let out through a valve at the top of the balloon. Suppose the balloon is now about 5lbs. heavy, it will begin to fall slowly. As it falls the atmospheric pressure increases and the gas contracts in volume. There is now a definite mass of gas in the balloon, and this displaces a definite mass of air. Therefore, irrespective of the volume occupied by the gas, the effective lift remains the same throughout the descent provided the temperatures of the hydrogen and the air are the same. So theoretically our balloon will reach the ground 5lbs. heavy.

In practice, however, it will be found that if a balloon is allowed to fall unchecked, a comparatively heavy expenditure of ballast will be required to bring her to rest. This is due mainly to the fact that the gas does not readily take up the temperature of the surrounding atmosphere. The ballast reserved for checking the descent of a balloon or airship is known as "landing ballast."

Reverting to our balloon of 1,360lbs. gross lift and 620lbs. fixed weight, we have seen that 306lbs. of discharged ballast corresponds to about 8,000ft. altitude. Clearly, instead of losing gas and ballast during the ascent, the same altitude could be reached by inflating only 80 per cent. full, *i.e.*, saving 4,000 cubic feet of hydrogen and carrying 4 × 68lbs. = 272lbs. less ballast. The balloon would now be balanced on the ground with a

Gross lift 16 × 68	=	1088lbs.
Fixed weights (as before)		620lbs.
Ballast		468lbs. instead of 740.

We should now reach 8,000ft. with the discharge of 34lbs. of ballast, the gas expanding as the balloon rises, and at about 8,000ft. the balloon will be in exactly the same condition as when she started fully inflated. Therefore, provided a balloon will lift all that is required for the flight and the landing, there is no need for it to be fully inflated. The height to which such a balloon can go before any gas escapes at the neck is referred to as the pressure height.

In a rigid airship automatic gas valves correspond to the neck of a balloon, and when the pressure height is reached, hydrogen escapes through these valves.

At any height below the pressure height an airship can manœuvre without loss of gas. If a ship rises above the pressure height, gas escapes and we get a new pressure height corresponding to the maximum height to which the ship has gone.

The foregoing remarks outline the general principles governing the flight of a balloon, and apply to all types of airships.

It is now proposed to describe briefly the various distinctive types of airships —non-rigid, semi-rigid and rigid.

Non-Rigid Airship.

A non-rigid airship is one in which the shape of the envelope is maintained solely by the internal pressure of the contained hydrogen. It is virtually a balloon with a power unit suspended, the envelope being streamlined in shape in order to reduce head resistance.

In order to maintain the hydrogen pressure during the descent of a non-rigid airship, air ballonets are fitted inside the envelope so that air at a pressure occupies the space of the hydrogen lost during the ascent.

The ballonets may be inflated by means of a blower driven from the power car or by means of an air duct led away from the propeller slip stream.

If the ballonets are empty on leaving the ground, they would remain so throughout the ascent. The hydrogen would be at a pressure sufficient to preserve the shape of the envelope. The automatic gas valve, which is virtually a safety valve, would be set so as to release hydrogen when the pressure becomes about 30 m/m. of water above the atmospheric pressure. Hydrogen, of course, escapes through the valve during the ascent as in the case of a balloon, but the internal pressure is maintained at 30 m/m. above the pressure of the external atmosphere.

On descending the gas contracts and the ballonets come into operation. The ballonets are fitted with automatic valves set to work at a lower pressure than the gas valves. This arrangement prevents gas being forced out when the ballonets are inflated, and it also ensures that air and not hydrogen is expelled, should it become necessary to ascend after descending. This setting of valves ensures that the ship can operate below her pressure height without loss of gas, as in the case of a balloon.

The capacity of the ballonets is dependent on the maximum height to which the airship is designed to ascend. The capacity must be sufficient to fill the space of the hydrogen lost during ascent.

We have seen that a balloon at 8,000ft. has lost 22½ per cent. of its gross lifting capacity, this percentage being deduced from the percentage lift curve at varying altitudes. In a non-rigid airship this 22½ per cent. represents the minimum capacity of the ballonets corresponding to a maximum height of 8,000ft. After descending from such a height the ballonets would be just full.

Semi-Rigid Airship.

A semi-rigid airship is one in which the longitudinal strains are taken by a specially built girder fitted along the underside of the envelope. The envelope pressures can by this means be reduced as compared with those for a non-rigid airship, and this admits the use of a lighter fabric. This saving in weight of fabric compensates partially, or perhaps completely, for the weight of the girder introduced. The semi-rigid type of design due to the introduction of a longitudinal girder lends itself conveniently to the adoption of some rigid support to the bow. It also enables the fins, rudders and elevators at the after end to be more rigidly supported than in the case of the non-rigid ship. Some very successful types of semi-rigid airship have been produced by the Italians.

Rigid Airship.

It is now proposed to describe rather more fully the rigid airship. Non-rigid and semi-rigid airship designs have distinct limits to their cubic capacities. With a rigid airship we have quite a different proposition, and the limit to capacity has certainly not yet been reached; in fact, it is difficult to say what will eventually be the limiting factor in the design of a rigid airship as the gross capacity is increased.

The rigid airship consists of a hull framework that is designed to take all the bending moments and shearing forces that arise. The hull framework encloses the gasbags, the whole being enclosed by an outer cover which is supported by the girder work and the wiring of the hull.

The gasbags and outer cover play no part in the designed structural strength of the ship. The gasbags are merely containers for hydrogen, and are made of very light fabric rendered as gastight as possible by means of a lining of goldbeaters' skins. The gasbags, owing to their lightness, have to be carefully supported by means of wiring or netting.

The outer cover similarly is a relatively light fabric, its function being to give a fair outer surface and to protect the gasbags from exposure.

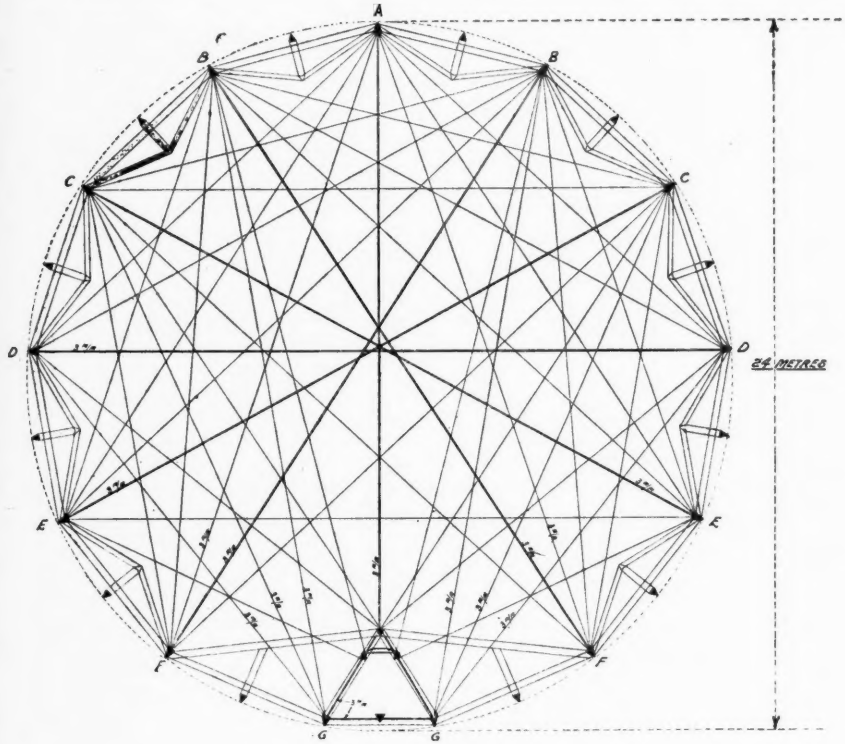


FIG. 2.

H.M. Airship R.34 might be taken as being typical of a modern rigid airship, and the principal dimensions of this ship are as follows :—

Capacity	... ...	2,000,000 (approx.) cub. ft., which corresponds to—
Gross lift	... ...	60 tons.
Fixed weight	... ...	About 31 tons.
Useful lift	... ...	About 29 tons.
Overall length	... ...	645 feet.
Maximum diameter	...	78ft. 9in.

The hull consists of 19 main transverse frames spaced generally 10 metres apart. Those amidships are shaped as polygons of 25 sides, and have a circumscribing circle of 78ft. 9in. diameter.

There are 13 main longitudinals and 12 intermediate longitudinals connecting the main transverse frames. These 25 longitudinals form the edges of the 25-sided polygonal form. Between two consecutive main transverse frames there is a 25-sided intermediate transverse frame.

Main transverse frames are wired in their plane in order to preserve transverse rigidity. The gasbags, of which there are 18, fill the spaces between the 19 main frames.

The panels of the outer surface of the hull formed by the longitudinal and transverse girders are cross-braced with the two distinct systems of wiring known as

(*a*) Major diagonal wiring.
(*b*) Minor diagonal wiring.

Inside the hull built up from the two bottom longitudinals is a corridor running practically the whole length of the ship. This corridor serves as a gangway for the purpose of getting from one car to another, or to any desired part of the ship. The corridor also serves as a longitudinal girder for the carrying of petrol tanks and water ballast bags, which are distributed throughout the length of the ship.

The corridor girder is supported at each main transverse frame by wires leading to the top of the ship. In this way the local loads to which the corridor is subjected are distributed to the various main joints in the upper parts of the hull structure.

At the after end of the hull structure horizontal and vertical fins are fitted in order to stabilise the motion along the longitudinal axis. At the after end of each fin is a rudder or elevator plane operated mechanically from the forward control car. By means of these planes the ship can be manœuvred. The fins, rudders and elevators are built up of girders, the surfaces being covered with outer cover fabric.

Girders.

The girders comprising the hull structure are of various types and sizes depending, of course, on the particular work for which they are designed. Generally they are triangular in section and formed by longitudinal duralumin channels at the three corners of the section, each face of the girder being cross-braced by means of light duralumin stampings. A relatively strong girder per lb. of weight can be obtained in this manner.

Duralumin.

Duralumin is used generally for the hull structural work, and this material is an alloy of aluminium, its composition being :—

Aluminium		94%
Copper		4—4½%
Magnesium	.65	1½—2%
Manganese	.50	
Silicon	.50	
Iron	.30	

Its S.G. is 2.79, which gives it a weight of .102lbs. per cubic inch. Its melting point is 650°C., and its coefficient of linear expansion is .0000226.

It has an ultimate tensile strength of about 25 tons per square inch with an elongation of 20% in 2in. The elastic limit is about 14 tons per square inch. It can be manufactured up to 35 tons per square inch with very little elongation.

Young's modulus (E) for duralumin is about 4,700 tons per square inch. The yield point in tension is about 20 tons per square inch and in compression about 10 tons per square inch. In compression duralumin is weight for weight approximately of the same strength as steel.

Gasbags.

Gasbags are made of skin-lined rubber-proofed cotton fabric. The plain cotton fabric weighs 65 grams per square metre, and has a rubber proofing of 20 grams per square metre on one face. This face is lined with goldbeaters' skins, these being light strong skins highly impermeable to the diffusion of hydrogen. The finished weight of the skin-lined fabric is about 150 grams per square metre.

Each gasbag is fitted with an automatic gas valve at or near the bottom of the bag, and for the parallel portion of the ship this valve is set to blow at a gas pressure at the bottom of the bag of 5 m/m. of water in excess of atmospheric pressure. This pressure, it will be realised, is a very low one. It corresponds to .0071lbs. per square inch or approximately 1 lb. per square foot.

A gasbag fitted in the parallel portion of R.34 is about 24 metres, *i.e.*, approximately 78ft. in diameter and with 5 m/m. of water pressure at bottom of such a bag, the excess pressure at the top due to the differences in density of air and hydrogen would be 31 m/m., or approximately 6¼lbs. per square foot. Very approximately the pressure in a gasbag increases 1 m/m. of water for each metre of vertical distance.

It will be observed that although these pressures are small when compared with atmospheric pressure, the areas subjected to these gas pressures are relatively large. Naturally, if we integrate the upward excess pressures we get the gross lift of the airship, which in the one described amounts to 60 tons.

The area of the transverse end of a gasbag in the parallel portion is about 4,800 square feet, and if we take a pressure of 5 m/m. at the bottom, the average pressure over the end is about 18 m/m. of water, which corresponds to a total end pressure of nearly 8 tons. With a neighbouring gasbag deflated, or partially deflated, the supporting of this end pressure becomes a most serious problem, on which it is proposed to remark further in the second lecture.

At the ends of the ship the gasbags are naturally smaller in diameter, and the automatic gas valves are set to correspond to a higher pressure at the bottom of the bag. If the setting of automatic gas valves corresponds to the actual heights of the various valves above a level line, then it is clear that at the pressure height gas would be blowing from all bags simultaneously.

Top or manœuvring gas valves are fitted to about one half of the total number of bags and are operated from the control position. These valves correspond to the top valve in a balloon and enable the equilibrium and trim to be adjusted should the ship become light due to the consumption of petrol and oil.

Outer Covers.

The outer cover is made up in panels of doped linen or cotton, the separate panels being stretched tightly and laced to the main girders of the hull. The fabric is usually doped before being made up into panels, and the completed outer cover is finally doped in place at the ship. The function of the dope is to preserve watertightness, and the coating in place assists the tautening of the cover.

The outer cover must be attached wherever possible to the various diagonal wires by means of lacing strips fixed to the inner surface of the fabric.

The finished outer cover weighs about 140 grams per square metre.

The outer cover of an airship has several important functions. It has to be taut in order to give a fair outer form. If the cover is slack it begins to flap during flight and this appreciably increases head resistance. The cover also must be well doped as otherwise the amount of moisture absorbed by the fabric will be considerable. The cover, too, must protect the gasbags from superheating, *i.e.*, it must reflect the heat rays, and to meet this requirement aluminium powder is usually mixed with the final coating of dope.

Special care is taken to provide extra support for the outer cover in wake of the propellers.

Machinery.

The power units are located in cars that are suspended below the ship at various points. Airship R.34, of which the dimensions have been given, has four power cars—one forward, two amidships and one aft. The after car contains two 250 h.p. engines geared to drive one propeller. The other power cars each contain one 250 h.p. engine. The two wing car units are fitted with reverse gearing. Petrol is supplied to the power cars from service tanks carried in the corridor.

General.

The ship is navigated from a control car forward and from the control position, engine telegraphs and telephones are arranged to all power cars.

The rudders and elevators are operated from the control car, and auxiliary operating positions for these main controls are provided in the after power car.

The top gas valves and the water ballast valves are also controlled from the navigating position. The ordinary water ballast is carried in fabric bags, each containing about one ton of water, and from each bag water can be discharged at the rate of about 1½ gallons per second. At positions forward and aft, emergency water ballast bags are provided, and these are fitted with special release arrangements that enable about one ton of water to be discharged from each position in a very few seconds. This emergency water is usually reserved for landing, should a ship have an excess of downward momentum when near the ground.

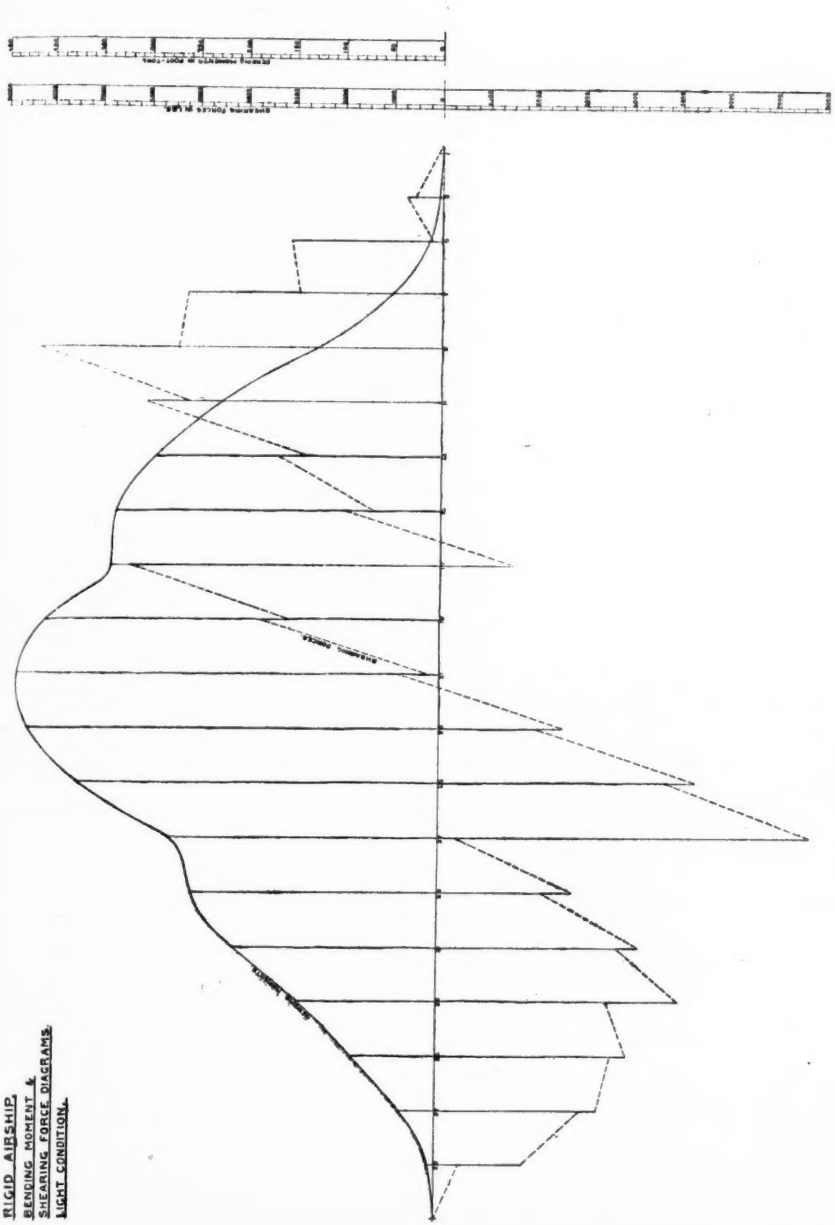
This concludes the general description of a modern rigid airship, and in the second lecture it is proposed to examine some of the more important features connected with the design of such a ship.

LECTURE II.

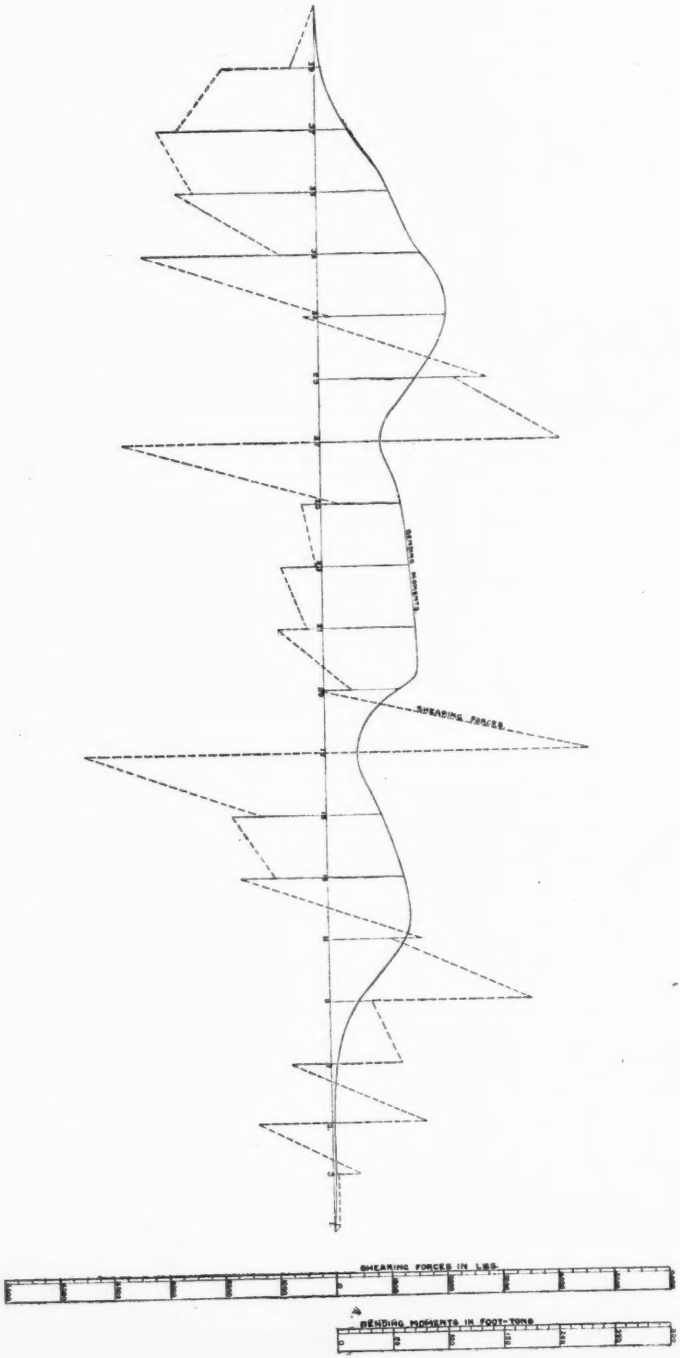
Introduction.

In this lecture it is proposed to refer to some of the more important problems that have to be considered in the design of a rigid airship. A designer might be limited to size by considerations of first cost or the dimensions of sheds available. His problem is to produce for any given gross capacity the largest possible useful lift without sacrificing the structural strength necessary for airworthiness and to provide for a reasonable air speed to enable the ship to make headway against winds that are likely to be encountered.

We have seen in the first lecture that a ship of two million cubic feet capacity has a gross lift of about 60 tons, and that with such a gross capacity the length is 645ft. and the diameter 78ft. 9in. The designer's problem is to provide a structure of these dimensions capable of resisting all the strains to which it might be subjected, to fit machinery capable of propelling it through the air at about 60 miles per hour, to fit gasbags, outer cover, petrol system, control arrangements



RIGID AIRSHIP.
BENDING MOMENT & SHEARING FORCE DIAGRAMS.
LIGHT CONDITION.


BENDING MOMENTS
SHEARING FORCES
SHEARING FORCES IN LBS.
BENDING MOMENTS IN FOOT-TONS

and equipment, using as little as possible of the 60 tons of gross lift, the usefulness of the completed article depending mainly on the amount of the 60 tons available after all the above requirements have been fulfilled. An airship designer, therefore, has to be particularly careful to economise weight in every detail and to see that as far as possible every pound of weight worked into the hull structure contributes to the strength of the ship.

Stresses to which the Hull Structure is subjected.

With these preliminary remarks we will proceed to consider generally the stresses to which the hull of a rigid airship is subjected.

The completed ship might be considered as a girder, and due to the differences in distribution of weight and buoyancy it becomes subjected at each point of its length to a bending moment and a shearing force. The distributions of weight and buoyancy are plotted graphically on a base representing the ship's length, and from these two curves a resultant load distribution curve is deduced. The first integral of the load distribution curve gives a shearing force curve, and the integral of the shearing force curve gives the bending moment curve. From these last two curves we can determine the bending moment and shearing force at any section of the ship. Knowing the bending moment at any section, the stresses in the various longitudinals can be determined from the formula "$p = My/I$," I being the moment of inertia about the neutral axis of all materials in the section that contribute to longitudinal strength.

Such curves as these briefly described are drawn for two main conditions :—

(1) Ship fully loaded and fully inflated, *i.e.*, the heavy condition.

(2) Ship lightened as far as possible by the discharge of all disposable weights except those necessary for landing, the gasbags being correspondingly deflated in order to balance the ship.

The condition that the ship must be floating on an even keel in each of the above cases amounts to saying that the total area of the load distribution curve is zero and the centres of areas of the buoyancy and weight curves are in a line at right angles to the base.

Bending moment and shearing force curves * for a modern rigid airship in the heavy and light conditions are shown in Figs. III. and IV.

Distribution of Vertical Shear.

The shearing force at any section in the parallel portion is taken by the diagonal wiring. In this lecture we must confine ourselves to the vertical shearing forces, but it must be borne in mind that considerable shearing forces and bending moments are brought about in a horizontal plane when a ship is turning in the air or being handled on the ground. The greatest proportion of the vertical shearing force at any section of the parallel portion is taken by the diagonal wires nearest to the horizontal plane through the neutral axis.

At the tapered ends of the ship a certain proportion of the vertical shear is taken by the longitudinal girders.

The method of determining the distribution of shearing force at a section in the parallel portion, assuming the simplest case of one system of diagonal wires, is outlined in Appendix I.

By means of the formula $T = \dfrac{FLA \sin\theta}{D\Sigma A \sin^2\theta}$ we can determine in this simple case, the stresses to be borne by the various diagonal wires due to vertical

* Curves taken from Mr. C. J. Campbell's Paper, Transactions, Institute of Naval Architects, 1919, "Development of Airship Construction."

shearing force, and it is on these general lines that the sizes of the wires in the diagonal systems are determined.

One might add that besides drawing curves of bending moment and shearing force for the heavy and light conditions, the designer usually produces a set of curves, assuming each gasbag separately deflated. The deflated bag condition is severe, but as regards longitudinal strength the hull structure is designed to withstand the stresses that would arise as the result of any one bag being totally deflated. The most serious aspect of the deflated bag condition will be referred to later.

Longitudinals with Lateral Load.

So far we have considered the longitudinal girders of the ship only as acting as struts or ties to resist the bending moment across any section. These girders however are also subjected to a lateral load due to the gas pressures, these gas pressures being applied by the gasbags themselves or transmitted to the girders by the gasbag netting. At the top of the ship when the gasbags are fully inflated, *i.e.*, in the heavy condition, these lateral loads are considerable. In the light condition, due to the gasbags being at a less degree of inflation, the lateral loads are relieved to some extent, but as in all conditions the upper longitudinals are subjected to a lateral load, it is most important that the bending moment should be such as to put these longitudinals in tension and not in compression, *i.e.*, the ship should be " hogging " in all conditions. Also as lateral loads are most severe in the heavy condition, the bending moment for that condition should be as small as practicable. Petrol and water ballast in a rigid airship are distributed by the designer so that in the heavy condition the bending moment curve is one of the smallest possible ordinate. The worst bending moments arise in the light or deflated bag conditions, but in these conditions the lateral loads are not so severe. Any excessive bending moment or shearing force in the light condition can only be relieved by a re-arrangement of distribution of fixed weights.

As we have already seen it is desirable to have the ship " hogging " in all conditions. This puts compression on the lower longitudinals of the ship. The condition here, however, is relieved by the fact that the longitudinal structure of the corridor can be arranged to take its proportion of the stresses.

With this brief survey of the method of arriving at bending moments and shearing forces in any condition and the consideration of various loads brought to bear on the girders and the wires due to the longitudinal bending moments, shearing forces, and the gas pressures, we will pass to the consideration of the wiring of a transverse frame, and will discuss the more important stresses to which transverse girders are subjected.

Stresses in Transverse Wiring and Transverse Girders due to Differences in Gas Pressures of Two Consecutive Bags.

Generally, all main transverse frames are wired with a system of radial and chord wires. The main stresses in the transverse frame arise when one gasbag is more fully inflated than its neighbour, the extreme case being when one bag is full and the next one empty. With a deflated bag the whole of the end pressures of the neighbouring gasbags have to be taken primarily by the transverse wiring, and the tensions thus put into these wires are transmitted to the joints causing compression in the girders of the transverse frame. It is the consideration of the deflated bag condition that governs the strengths of the transverse framing and wiring that is required.

Consider a system of radial wiring, *i.e.*, wires coming from a central ring to each of the main joints of the transverse frame. Such a system was fitted in the earlier British rigid airships.

When the end pressure of a gasbag has to be supported by this system of wires clearly the only longitudinal support is the sum of the resolutes of the wire tensions along the longitudinals at each joint.

The more the wires are bulged out the less becomes the angle of the wire at the joint to the longitudinal direction. Thus if wires can be fitted that will stretch sufficiently it becomes practicable to support the gasbag end pressures by virtue of the bulging out of the wires until the sum of the longitudinal components of their tensions balances the gasbag end pressure.

We will now consider for a few moments the mathematical investigation of the transverse wire tensions in the deflated bag condition assuming a perfect radial system of wires. (See Appendix II.)

Examination of the equations arrived at in Appendix II. by taking some concrete cases will demonstrate that with steel wires fitted radially it is virtually impracticable to support the end pressure of a gasbag more than about 50ft. in diameter, the main trouble being the enormous compression thrown on the girders of the main transverse frame. Consequently, with modern airships special means have to be adopted to cope with this problem, and there are two main alternatives that suggest themselves.

(1) The fitting of a longitudinal axial wire, whose function is to restrain the axial movement of the centre ring, *i.e.*, to make $y_0 = O$ in the equations (Appendix II.).

(2) The fitting of wires, that in the event of the whole end pressure having to be supported, would be strained to a point just beyond the elastic limit of the material, at which point the relatively large extension would admit of a considerable axial movement of the centre ring. The effect of this is to confine the wire tensions, and therefore the compressive stresses on the main transverse girders to within reasonable design limits, the longitudinal resolute of the wire tension at the joints being increased due to the more favourable angle that the wire makes with the longitudinal at the joint. For this treatment of the problem, duralumin wires would probably give the best solution, duralumin having a low elastic limit when compared with its yield point or its breaking point.

The first solution has been adopted in British designs for ships of relatively large diameter, the axial wire running longitudinally through all the gasbags and connecting the centre rings of the transverse wiring.

In addition to the pure radial system of wiring, chord wires are introduced, and these serve to break up the otherwise unsupported portions of the gasbag surface.

The horizontal component of the wire tension at the joint is determined by putting $x = r$ in equation (6) (Appendix II.), and this gives $-T\,dy/dx = \frac{2}{5}Kr^3 \tan\alpha + Ty_0/r$, and using this equation in association with curves of T and y we find values that will satisfy the condition of equilibrium, that the sum of longitudinal components of T shall balance the total end pressure of the gasbag.

The mathematical treatment and the formula arrived at apply only to a perfect radial system. The introduction of chord wires must affect our results, as these wires are assisting in the transmission of pull to the joints and their effect is to reduce the tension in the radial system. In consequence, our formulæ give absolute maximum values of the various stresses and are of considerable importance to the designer when used in conjunction with observed wire tensions for various degrees of gasbag inflation. Experiments have frequently been carried out on rigid airships, where isolated gasbags have been inflated, the corresponding wire tensions being recorded. This test is perhaps the most severe structural test to which a rigid airship can be subjected.

With an airship in flight, the excessive strains that would arise should one bag become deflated would be relieved considerably by letting down the neighbouring gasbags so as to distribute the strains equitably amongst 3 or 4 transverse frames.

We have so far outlined some of the main stresses to which the various girders of the hull are subjected. We will now consider for a moment the various types of girders used in R.34 and their functions. We will also discuss the general method of girder design.

Girders.

We have seen that longitudinal girders have to withstand lateral load as well as tension or compression. They are therefore made isosceles in section, and placed apex outwards. The two base channels of the girder resist the compression due to the lateral load, the apex channel being in tension. As duralumin has a yield point in tension of about 20 tons per square inch, and in compression of about 10 tons per square inch, it will readily be seen that the apex out arrangement is the most favourable aspect for equitable stress distribution.

Superimposed on the stresses induced by the lateral load, we have the tension or compression due to the static bending moment that we discussed when we were considering the whole ship as a girder.

When a girder is in tension or subjected to a lateral load, calculations of stresses in the channel members do not present any serious difficulties.

The design of a girder to act as a strut is perhaps best considered in connection with experimental results of tests on duralumin sections.

If a section of duralumin channel or angle be tested in compression, it is found that if L/k is large (say, over 150), the strut fails at loads that very nearly approach those given by Euler's formula $P = \pi^2 EI/L^2$.

At lower values of L/k the crippling stress, as might be expected, falls away from that given by Euler's formula. At certain values of L/k a discontinuity might appear in a curve of failing stress plotted on a base of L/k. This discontinuity is due to failure of the exposed edges of the channel or angle. It has been demonstrated that this secondary flexure can be avoided if the ratio of the thickness to the depth of the flange of the angle or channel is greater than about 1/10. This figure, however, depends to some extent on the actual value of L/k.

Another method of avoiding secondary flexure is to turn in and thus stiffen the exposed lip flanges of the section.

Girders that have to stand pure compression are generally of equilateral triangular section. The main transverse girders are built up of equilateral triangular sectioned girders, kingposted as shown in Fig. V. The kingpost is in the centre of the girder and is attached to the intermediate longitudinal. This arrangement, besides making the girder strong in compression, enables lateral load on intermediate longitudinals to be transmitted through the kingpost trusses to the main joints without causing any serious lateral load on the main compression member of the transverse girder.

In designing a braced girder to act as a strut, the following considerations must be borne in mind:—

(1) Theoretically the strongest strut of any specified length is the one with the largest possible moment of inertia of section.

(2) Expressing the moment of inertia of the section as Ak^2 [area × (radius of gyration)^2], the most efficient method of getting a large moment of inertia is to increase k. The weight of the channel members of a girder of given length varies as A, and therefore for an efficient load per unit weight of channel, A should be small, the inertia being obtained by increasing k.

(3) To avoid secondary flexure there is a practical limit beyond which A cannot be reduced. The flange of the channel must be deep enough to enable bracing pieces to be riveted on to it, and the thickness of the flange must increase with the depth if secondary flexure is to be avoided.

(4) As the strength of struts is a function of L/k, it is clear that the L/k of the small length of channel unsupported by bracings must not be greater than the L/k for the whole girder. Therefore as k for the whole girder increases, the span of the bracing pieces would tend to become less, *i.e.*, the number of bracings increases with an increase of k for the whole girder. Also as k increases the lengths of the bracings increase; hence we may say that approximately the weight of the bracing pieces increases with the k^2 of the girder.

Now our problem is to design a strut of required length that will take the greatest load per unit weight of material. Considerations (1) and (2) above favour a large radius of gyration, whilst (3) and (4) favour a small radius of gyration, so of necessity the result is a compromise, and the most efficient type of strut must be eventually designed from experimental data supplemented as necessary by theoretical considerations.

There are several good formulæ that might be used for comparing the strengths of similar struts, these formulæ of necessity containing experimentally determined constants that allow for the facts that struts are never perfectly straight nor axially loaded; neither is the material homogeneous nor isotropic.

Airship girders have values of L/k generally between 40 and 50, and the total load that the girder will stand in compression might be taken as being 10 tons per square inch of material in the cross section. It must be observed, however, that the best values of L/k and crippling stress vary with different types of girders and can therefore be accurately determined only from experiments on the particular type of girder under consideration.

Perhaps the best method of tabulating the results of strut tests is to plot the crippling stress per unit of sectional area on a base of L/k.

Form and Resistance.

We will now pass on to consider briefly the question of outer form and resistance.

There is no satisfactory method of accurately calculating the resistance of an airship form at various speeds and the designer instinctively turns to the consideration of model experiments. Such experiments are of great value to the naval architect in the determination of the resistances of surface craft.

There are, however, some subtle differences between model experiments as applied to airship resistances and model experiments for the determination of the resistances of surface craft. Naval architects, by measuring the pull necessary to draw a model across a tank, can predict only the wave-making resistances of a ship with any degree of accuracy, and this prediction is based on Froude's law of comparison, which does not apply to surface friction, nor can it be correctly applied to resistance due to eddies.

In an airship we have the case of vessel totally immersed in a fluid, and therefore surface wave-making resistance does not enter into our consideration, the causes of resistance being essentially due to surface friction and eddies.

It therefore becomes necessary before the results of model experiments can be usefully interpreted to develop a law of comparison for the surface frictional and eddy-making resistances of totally immersed similar bodies.

The general formulæ for the resistances of any form moving totally immersed through a fluid and the conditions for similarity of flow around geometrically similar bodies are developed in the manner indicated in Appendix III.

The method adopted at the National Physical Laboratory in order to test an airship form is to measure the resistance of a model in a wind tunnel and to determine the value of the coefficient, C, in the formula $R = \rho C V^2 L^2$ (see Appendix III.) for varying values of VL.

In order to criticise a shape this method gives satisfactory results, but as VL on the model, due to practical limitations, is much less than the VL of the ship, it is of relatively little value as a method of computing the total ship resistance, it not being known how C varies as VL increases. C is really a dimensional function of the variable $\rho VL/U$.

Various shapes have been tested at the N.P.L., and in a most interesting paper on this subject contributed by Mr. Pannell, published in the September issue of the AERONAUTICAL JOURNAL, the following conclusions are arrived at :—

(1) A form of tail $2\frac{1}{2}$ diameters long gives as low a resistance coefficient as any tail yet examined.

(2) A form 4.6 diameters long can be produced which will give a resistance coefficient of .007 at $vl = 60$ feet square per second. (It might be observed here that the similar coefficient for a form such as R.34 is .011 at $vl = 60$.) The forward curved portion of such a body may be elliptical and must be at least two diameters long. There should be no cylindrical portion.

(3) The introduction of cylindrical body generally causes an increase of resistance coefficient at higher values of vl.

(4) In forms of more than one diameter cylindrical body, a tail 2.75 diameters long may be used without appreciable increase in resistance coefficient.

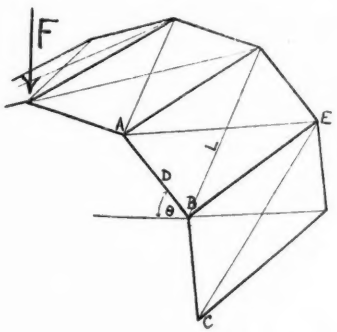
Results such as these are extremely useful and indicate to a designer what probably would be the ideal form for an airship. It must be clearly understood, however, that considerations other than form must enter into the problem of design, and if an ideal form requires an increased hull weight, due perhaps to the increased strength required in transverse frames, it is conceivable that a ship might be ideal in form and yet far from ideal as regards the percentage of the gross lift that is available for useful load. This is pointed out merely to indicate that a designer has to compromise and hold a balance between various conflicting ideals.

It is important to note that the condition for similar flows is independent of the type of fluid, and the total resistance of an airship might be predicted from experiments on a model totally immersed in water or other fluid. As it is impracticable in a wind tunnel to attain a value of vl, anything comparable to the vl of a full-sized airship, it is possible that for quantitative estimation of total resistance of an airship regular series of experiments will at some future time be carried out in a fluid where ρ/U is large compared with that of air, and if sufficiently large it will be practicable to reach values of $\rho vl/U$ more nearly approaching those for the full-sized airship than is at present feasible with a model whose resistances are measured in a wind tunnel.

In order to check the degree of reliability of all model experiments, whether in air or in a liquid, it appears essential to carry out towing experiments on a full-sized airship form. This would be following the precedent of William Froude, whose towing experiments in the " Greyhound " have firmly established the system whereby naval architects may predict from models the resistances of full-sized ships.

APPENDIX I.

DISTRIBUTION OF SHEARING FORCE ACROSS A SECTION.



The figure represents a portion of the outer surface of a ship with a simple system of diagonal wires.

Let θ = inclination of panel AE to the horizontal.
F = vertical shear taken from the curve of shearing force.
x = small vertical movement of frame ABC due to F.
L = length of diagonal wires.
D = length of transverse girder AB.

Then

$$L^2 = (D \sin \theta)^2 + K^2$$

where K is a constant for the panel. K is actually the horizontal projection of L.

$$2LdL = 2D \sin \theta \cdot d(D \sin \theta)$$
$$= 2xD \sin \theta \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If A be the sectional area of the wire and T its tension

$$T/A = EdL/L \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

From (1) and (2)

$$TL^2/EA = xD \sin \theta \quad . \quad . \quad . \quad . \quad . \quad (3)$$

D, L, E and x are constants for the section.

Therefore equation (3) becomes

$$T/A = c \sin \theta \text{ where } \text{“ } c \text{ ”} \text{ is a constant} \quad . \quad . \quad . \quad (4)$$

The shearing force F is the summation over the section of the vertical components of T.

Therefore

$$F = \Sigma Ac \sin \theta (D/L) \sin \theta \quad . \quad . \quad . \quad . \quad (5)$$

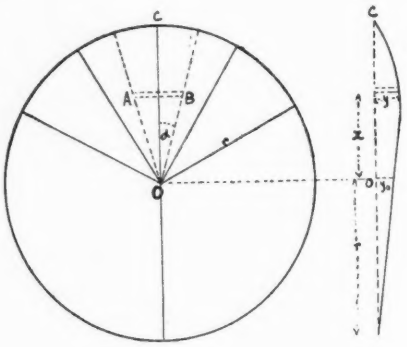
From (4) and (5) we have, eliminating “ c ”

$$T = FLA \sin \theta / D\Sigma (A \sin^2 \theta)$$

APPENDIX II.

TENSIONS IN RADIAL WIRES DUE TO GASBAG END PRESSURES.

Consider a pure radial system and assume that each wire supports the whole of the end pressure on a sector of angle 2α.



Gasbag pressure varies as $(r + x)$ if bag is just full.

Pressure on AB is given by equation

$$p = k\,(r + x)\,2x \tan \alpha dx$$

Equation of equilibrium of wire OC is

$$-T\,(d^2y/dx^2) = 2k\,(r + x)\,x \tan \alpha \quad . \quad . \quad . \quad . \quad (1)$$

where T is the tension in the wire.

$$\therefore\ -T\,(dy/dx) = 2k \tan \alpha\,(rx^2/2 + x^3/3) + C \quad . \quad . \quad (2)$$

$$-Ty = 2k \tan \alpha\,(rx^3/6 + x^4/12) + Cx + C' \quad . \quad . \quad . \quad (3)$$

When $x = 0$ $y = y_o$ $\therefore$ $C' = -Ty_o$.

Equation (3) becomes

$$T\,(y_o - y) = 2k \tan \alpha\,(rx^3/6 + x^4/12) + Cx \quad . \quad . \quad . \quad (4)$$

when $x = r$ $y = 0$

$$\therefore\ Ty_o = 2k \tan \alpha\,(r^4/4) + Cr$$

$$C = Ty_o/r - \tfrac{1}{2}kr^3 \tan \alpha$$

Equation (2) becomes

$$-T\,(dy/dx) = 2k \tan \alpha\,(rx^2/2 + x^3/3) + Ty_o/r - \tfrac{1}{2}kr^3 \tan \alpha$$

whence

$$(dy/dx)^2 = [(4k^2 \tan^2 \alpha)/T^2]\,[r^2x^4/4 + rx^5/3 + x^6/9] + y_o^2/r^2 + k^2r^6 \tan^2 \alpha/4T^2 + [4ky_o \tan \alpha/Tr]\,[rx^2/2 + x^3/3] - [2k^2r^3 \tan^2 \alpha/T^2]\,[rx^2/2 + x^3/3] - ky_or^2 \tan \alpha/T$$

Now the stretch of the wire OC, assuming no vertical movement of O is given by

$$1/2 \int_0^r (dy/dx)^2 \, dx$$

$$= \frac{1}{2} \begin{matrix} r \\ 0 \end{matrix} \left[\begin{matrix} [4k^2 \tan^2 \alpha/T^2] \, (r^2x^5/20 + rx^6/18 + x^7/63) + y_o^2x/r^2 \\ + [k^2r^6x \tan^2 \alpha/4T^2] + [4ky_o \tan \alpha/Tr] \, (rx^3/6 + x^4/12) \\ - [2k^2r^3 \tan^2 \alpha/T^2] \, (rx^3/6 + x^4/12) - [ky_or^2x \tan \alpha/T] \end{matrix} \right]$$

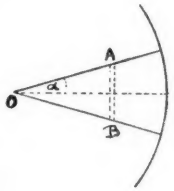
which simplifies down to

$$\text{Stretch of wire} = (33/280) \, (k^2 \tan^2 \alpha r^7/T^2) + (y_o^2/2r)$$

$\therefore$ If A = area of section of wire
E = modulus of elasticity

$$Tr/EA = (33/280) \, (k^2 \tan^2 \alpha r^7/T^2) + y_o^2/2r \quad . \quad . \quad . \quad (5)$$

For the *horizontal wire* we have



$$\text{Pressure on } AB = kr2x \tan \alpha dx$$

Proceeding as for vertical wire we get

$$-T \, (dy/dx) = 2kr \tan \alpha \, (x^2/2) + Ty_o/r - (kr^3/3) \tan \alpha \quad . \quad . \quad (6)$$

$$\text{Stretch} = 1/2 \int_0^r (dy/dx)^2 \, dx$$

$$= y_o^2/2r + (2/45) \, (k^2r^7 \tan^2 \alpha/T^2) \quad . \quad . \quad . \quad . \quad (7)$$

For the *lower vertical wire*

$$\text{Stretch} = y_o^2/2r + (17/2520) \, (kr^7 \tan^2 \alpha/T^2)$$

So we have the three equations

Top wire	...	$Tr/EA = y_o^2/2r + (33/280) \, (k^2r^7 \tan^2 \alpha/T^2)$
Horizontal wire		$Tr/EA = y_o^2/2r + (2/45) \, (k^2r^7 \tan^2 \alpha/T^2)$
Bottom wire	...	$Tr/EA = y_o^2/2r + (17/2520) \, (k^2r^7 \tan^2 \alpha/T^2)$

These equations assume no vertical movement of O, the centre ring. Actually O would move slightly upward equalising the tensions in the top and bottom wire. Now the mean of these two tensions is very approximately that given by the equation for the horizontal wire.

Therefore it is assumed that the movement of O is such as to make all the wire tensions equal to that given by the formula

$$Tr/EA = y_o^2/2r + (2/45) \, (k^2r^7 \tan^2 \alpha/T^2)$$

The introduction of an axial wire might be assumed to make $y_o = 0$ and our equation becomes

$$Tr/EA = (2/45) \, (k^2r^7 \tan^2 \alpha/T^2)$$

$$\text{or } T = C \sqrt[3]{A} \tan^{2/3} \alpha \, . \, r^2$$

APPENDIX III.

RESISTANCES OF SIMILAR BODIES MOVING THROUGH FLUIDS.

Let ρ = density of fluid $\left[\frac{M}{L^3}\right]$

U = coefficient of viscosity $\left[\frac{M}{LT}\right]$

V = velocity $\left[\frac{T}{L}\right]$

R = resistance $\left[\frac{ML}{T^2}\right]$

L = length or linear dimension indicating the scale of the body.

Viscosity per unit density is known as "*kinematic viscosity*" and resistance per unit density as "*kinematic resistance*," so let

$$v = U/\rho = \text{kinematic viscosity } \left[\frac{L^2}{T}\right]$$

$$F = R/\rho = \text{kinematic resistance } \left[\frac{L^4}{T^2}\right]$$

The kinematic resistance to motion through a fluid, of a totally immersed body, depends on v, V and L.

So we may write generally

$$F = cv^pV^qL^r \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Writing this equation dimensionally we have

$$\frac{L^4}{T^2} = c\,\frac{L^{2p}}{T^p}\,\frac{L^q}{T^q}\,L^r$$

whence

$$4 = 2p + q + r$$
$$2 = p + q$$
$$\therefore\ q = r \text{ and } p + r = 2$$

so our equation (1) becomes

$$F = cv^pV^rL^r \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$
where $p + r = 2$.

CONDITION FOR SIMILAR FLOWS AROUND GEOMETRICALLY SIMILAR BODIES MOVING THROUGH FLUIDS.

Using notation as above.
Type of flow depends on v L and V.
Write

$$L = cv^pV^q \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Dimensionally

$$L = c\,\frac{L^{2p}}{T^p}\,\frac{L^q}{T^q}$$

$$\therefore\ 2p + q = 1$$
$$p + q = 0$$
$$\therefore\ p = 1 \quad q = -1$$

So equation (3) becomes

$$L = cv/V$$

or $\rho VL/U$ = constant.

In the same fluid we might take ρ/U as being constant, then our condition for similar flows around similar bodies becomes

$$VL = \text{constant}.$$

Hence, *for a ship and model moving through the same fluid, totally immersed, the corresponding speeds vary inversely as the linear dimensions.*

Equation (2) gives

$$F = cv^pV^rL^r \text{ where } p + r = 2$$

and for similar flows VL/v = constant (say) K, so we have

$$F = c \frac{V^pL^p}{K^p} V^rL^r$$

$$= \text{constant} \times (VL)^{p+r}$$

$$= \text{constant} \times V^2L^2 \text{ since } p + r = 2$$

and since $F = R/\rho$

$$R = c\rho V^2L^2$$

where $\rho VL/U$ is constant.

In the same fluid v is constant and equation (2) might then be written

$$F = \text{constant } V^rL^r$$

and for similarity of flow in the same fluid we have VL = constant.

$\therefore$ Under these conditions F = constant.

R = constant.

That is, *in the same fluid and at corresponding speeds the resistances of a ship and its model are the same.*

REVIEW.

The Mechanical Principles of the Aeroplane. S. Brodetsky. (J. and A. Churchill.)

This book, intended for the use of University students, gives an account of the mathematical problems of the flight of an aeroplane and is divided into three main sections, dealing respectively with motion in air, dynamics of air and aeroplane motion. The quality of the book is curiously uneven and the author is happiest when dealing with purely mathematical questions. The discussion of periodic solutions of the motion of a body and of the various equilibrium conditions is very valuable, and the introduction to the theory of irrotational motion of a fluid is excellent. On the other hand, the lengthy discussion of discontinuous fluid motion is of very doubtful value in the science of aeronautics. In all practical problems the surfaces of discontinuity break up into a series of vortices, and this chapter of the book could be replaced with advantage by one dealing with circulation round a body and with simple vortex motion.

The chapters dealing with the aeroplane, as distinct from dynamics or hydrodynamics, appear to indicate insufficient experience of the real problems of aeronautics. Various statements are distinctly misleading, if not inaccurate, as for example when it is stated that an aeroplane is made to climb by increasing the speed and decreasing the thrust (p. 64). Also on p. 68 we read: "Since aerofoils have the property that for a certain angle of attack the L/D ratio begins to sink rapidly, the danger of flying too slowly, or of trying to climb too steeply, is obvious. This is called stalling the machine!"

As regards Section III. of the book, it is indeed true that the aeroplane has been idealised out of all recognition. A discussion of stability which ignores the movement of the centre of pressure and the downwash of the main planes may be interesting mathematically, but is worthless in aeronautics and must be misleading to the student, while the treatment of the problem of the airscrew suffers from similar defects and is very sketchy. "The Mechanical Principles of the Aeroplane" would have been a good book six years ago.

A final word must be said about the new system of notation introduced by the author. The particular merits of the scheme are by no means obvious. In the standard system it is easy to remember that Xu denotes the differential of X with respect to u, but there is no single connection between a_x or f_2 and the corresponding forces and velocities.

H. G.